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UDAC 86-023
10 July 1986

MEMORANDUM FOR: Director of Central Intelligence

THROUGH: Deputy Director of Central Intelligence
Director, Intelligence Community Staff
Deputy Director, Intelligence Community Staff
Director, CCISCMS

FROM: [redacted] 25X1
Chief, Unauthorized Disclosure Analysis Center

SUBJECT: IEEE Spectrum Article on Satellite Reconnaissance

This memorandum forwards, for your information, an article from the <u>IEEE Spectrum</u> magazine dealing with satellite reconnaissance. It is a compendium of information on intelligence gathering, a la Jeffrey Richelson, and [redacted] appears to consist of information that has been published [redacted] 25X1 25X1

[redacted] 25X1

Attachment: Article

~~SECRET~~

SUBJECT: IEEE Spectrum Article on Satellite Reconnaissance

Prepared by: C/UDAC/[redacted] 25X1

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IEEE
SPECTRUM

A SPECIAL REPORT:
The hide-and-seek of peacekeeping

Eyes in the skies □ The monitoring gaps □ The politics

THE PUZZLE OF CHERNOBYL

THE POLITICS OF PEACE PACTS

Technical monitoring capabilities are but part of the solution to arms control: attitudes of the superpowers are becoming more crucial

When considering the future of arms control, one must brush utopian rhetoric aside and accept that nuclear weapons are here to stay, say veteran arms controllers. When Mikhail S. Gorbachev proposes to banish nuclear weapons from the world by the year 2000, when Ronald Reagan declares his intent to render nuclear weapons "impotent and obsolete," experts like Milo Nordyke shake their heads and smile.

"The idea of a nuclear-weapons-free world is nonsense," said Nordyke, manager of arms control and verification programs at Lawrence Livermore National Laboratory. As arsenals shrink, the uncertainty that accompanies all verification methods becomes more and more critical, Nordyke said. "There is a level that you just cannot go below."

The question for the foreseeable future, according to Nordyke and others, is not, How can nuclear weapons be eliminated? but, How can they be controlled to reduce the threat of war? For those who believe the answer lies in verifiable treaties, the outlook is bleak. Technology is part of the problem. Remote sensing alone will be hard-pressed to track easily concealed, movable weapons like the cruise missile. But the growing role that politics has played in verification is even more critical.

There is near-unanimous agreement that—probably for technical reasons less than for political reasons—verifying future agreements will require so-called intrusive measures, which would permit the superpowers to station inspectors and sensors inside each other's borders. But the same distrust that spurs calls for these measures makes them difficult to negotiate. Moreover, experts like Nordyke stress that even if engineers devise some sensor that can peer through concrete, even if the superpowers exchange hordes of observers, there will always be a margin of doubt; there will always be those who seek to exploit this doubt, using verification to undermine rather than uphold arms control.

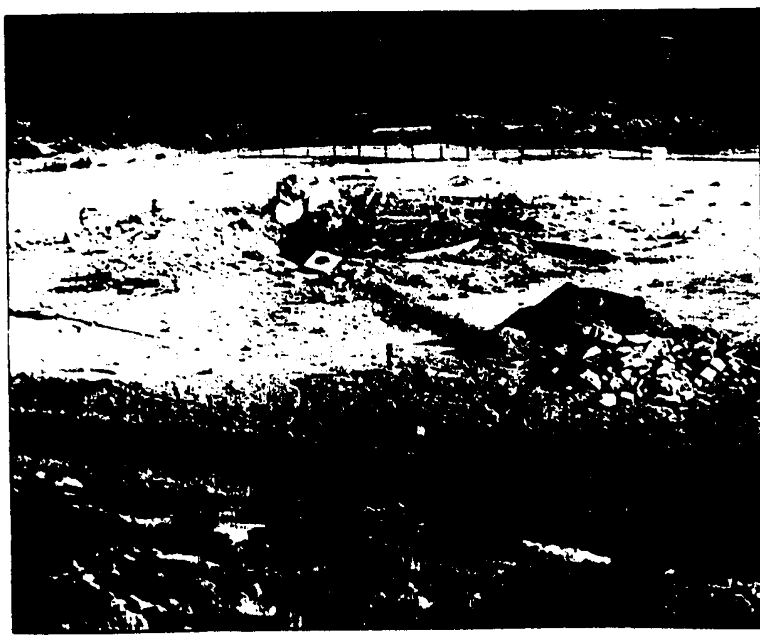
"There's this belief that somehow technology can sweep aside the mountain of political problems that has impeded the process over the years," said Roger Hagengruber, who as director of systems studies at Sandia National Laboratories oversees a number of verification projects. The advent of satellites like the Vela made the Limited Test Ban Treaty possible, but there is no comparable "technological rabbit to pull out of the hat today," said Hagengruber.

Hagengruber said that any "breakthrough" in arms control in the future will depend not on new technology but on changes of political attitudes within the Soviet Union and the United States. On the Soviet side, said Hagengruber, "the real breakthrough is going to be an increased understanding of the need for in-country activities." In the United States, he continued, "the breakthrough would be to avoid the polemical extremes that dominate the debate right now." On one side of the U.S. debate, Hagengruber said, are those who believe that arms control treaties can be "based on faith" and should be sought regardless of verifiability; on the other side are those who insist that unless a treaty can be "perfectly" verified, it is valueless. "The answer lies somewhere in between," said Hagengruber.

U.S. questions value of arms control

Even fervent believers in arms control acknowledge that the Soviets' record on compliance is not pristine. For example, few accept the Soviets' explanation that a radar facility under construction near the town of Krasnoyarsk is for tracking satellites and not incoming missiles, and thus is not a potential violation of the 1972 Anti-Ballistic Missile Treaty. Moreover, Soviet calls for a freeze and the elimination of nuclear weapons have not been accompanied by detailed proposals for verification, according to U.S. officials. Nevertheless, experienced negotiators contend that the Soviet infractions have little military significance, and that the USSR appears more willing than ever to meet U.S. concerns about verification.

But the Reagan administration has questioned the value of arms control for securing the nation. Past agreements have restrained only the United States, according to Administration officials, because the Soviets have violated most of them [see Tables I, II, and III]. In May, over the vociferous objections of Congress and allies in the North Atlantic Treaty Organization, President Reagan declared that the United States would no longer consider itself bound by the second Strategic Arms Limitation Talks treaty (SALT II), signed in 1979. Referring to the SALT II decision, Defense Secretary Caspar W. Weinber-



U.S. Department of Defense

Following SALT provisions, the United States has destroyed 27 ICBM launchers, like this Titan II silo; the USSR has dismantled 281 silos.

John Horgan
Associate Editor

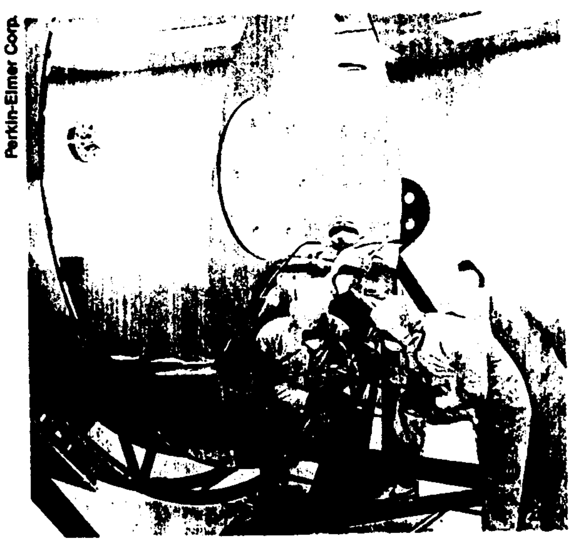
IEEE
SPECTRUM

VOLUME 23 □ NUMBER 7 JULY 1986

The U.S. Central Intelligence Agency's first "spy" satellite, dubbed Discoverer, could hardly have been called an instant success. The goal in early 1959 was to orbit the world's first photoreconnaissance satellite and to retrieve a film capsule ejected back into the atmosphere from space. But only after a dozen attempts over a year and a half did the mission finally work as planned. A U.S. Air Force plane (similar to the one at right) snagged the parachute of a film capsule in August 1960. The age of space surveillance had begun—a scant three months after U.S. pilot Francis Gary Powers was shot down in a U-2 spy plane over the Soviet Union.

U.S. Smithsonian National Air and Space Museum

Since then, the resolution capabilities of reconnaissance satellites have been vastly improved. With digital sensing and transmission of images, there is no need to recover film capsules. Details on spy satellites remain classified, but an orbiting satellite equipped with mirrors the size of the one in the civilian Hubble Space Telescope (below) could theoretically distinguish ground features 7 centimeters across.



Perkin-Elmer Corp.

Backed up by such technology—along with radars, electronic satellites, and seismic sensors—the superpowers have been able to enter into verifiable arms agreements. But whether monitoring technology can keep track of advances in offensive weaponry is questionable. *Spectrum* editors John Adam, John Horgan, and Glenn Zorpette visited Government laboratories, private companies and think tanks to help find out. Their report begins on p. 42.

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ARTICLES

Special analysis

Special report

DEPARTMENTS

THE COVER

Some of the world's first direct evidence of the Chernobyl nuclear reactor disaster came from Landsat data. In this image, generated from data collected three days after the accident, the blue pixel at the northwest corner of the left contour marks intense heat from the exposed and burning reactor core. Smoke spews to the west of the pixel. The contours show constant, relatively low temperatures, indicating the absence of fire or meltdown at adjacent reactors, a conjecture at the time. *See p. 34.*

Photo: Ocean Earth Corp./Sipa

SPECTRAL LINES

JULY 1986 / VOLUME 23 / NUMBER 7

Verification and arms control

It sometimes seems useful to compare the complexities of peacekeeping at an international level with those involving two neighbors.

Imagine your next-door neighbor collecting guns. If he displayed them openly, showed them off proudly, and occasionally used one for hunting small game, you would probably feel little or no threat. If, on the other hand, he was secretive and uncommunicative about the collection or its uses, you might feel a bit uncomfortable. Furthermore, if occasionally you were to hear an unexplained gunshot, about which he professed no knowledge, you might even feel prompted to begin a small firearms collection of your own.

If you felt really threatened, you might attempt to discuss the matter with your neighbor and, with his agreement, set some limit on the size or caliber of your individual collections and keep them in plain sight.

On the other hand, the very premise of a possible threat to either you or your neighbor would suggest that a less-than-friendly environment existed, along with at least some degree of mistrust. Could you ever be sure under such conditions that your neighbor was not producing explosive canisters in his basement and storing them out of sight just in case *your* motives were not completely aboveboard?

The very notion that a person or a nation feels it necessary to determine the extent, nature, and location of a potential adversary's weapons underscores the unstable nature of the relationship and suggests that it could be upset by even a minor misstep or slight misunderstanding.

Seasoned negotiators look in two distinct directions as they attempt to develop useful and reasonably long-lived international arms accords. They carefully watch the heads of state, often with trepidation, for signals that may alter the negotiating environment, or cause them to modify their own posture. They look also to the technologists for improvements in the monitoring capabilities that can strengthen the accords.

The objective of arms verification is to assure one or more of the countries signing an arms control treaty that the other(s) do not violate the agreement. Also, governments may be interested in knowing whether an adversary is marginally exceeding a treaty requirement so that they can use the information for propaganda purposes, or perhaps for leverage in other negotiations.

Radical shifts in peacekeeping strategies can make certain treaty provisions obsolete. Those approaches that ensure that neither party can protect against a massive attack are based on the strategic theory of stability through mutual deterrence. The Anti-Ballistic Missile Treaty, in force since October 1972, is a case in point. It is based on the theory of limiting the defenses against intercontinental ballistic missiles that might tempt adversaries to scale up offensive weapons to overcome the better defenses. It also prohibits one nation from gaining an advantage over another by escalating its defenses against a retaliatory strike. But a strategy of mutually assured defense—which is an aim of SDI—would require superior "eyes" for both sides, as well as means for destroying enemy missiles once an attack is detected. The switch from the former strategy to the latter would necessitate passing through a series of destabilizing steps and back again until ultimately stability is restored. Both sides would have to be sensitive to the end objective and tolerant of any transient treaty violations.

Arguments are frequently heard about which is more important: the politics or the technology of peacekeeping. In fact the two are handmaidens. Verification technology is merely a tool, albeit a vital one, in the peacekeeping arsenal of any nation or group of nations. The verification process itself may sometimes be a destabilizing influence. For example, based on improved monitoring technology, the United States strongly contends that the Soviets' SS-25 is a new missile, in violation of SALT II, while the Soviets disagree. The difference from the older SS-13 may be marginal, and might have been undetectable with earlier technology.

If there often seems to be little logic and much contradiction in peacekeeping efforts, it is because with so much at stake, actions and reactions take place at several levels. First, rhetoric at the leadership levels often bears little relationship to reality, but nevertheless sets the tone for the arena in which the practitioners of treaty negotiation must toil. Heads of state may posture; treaty makers may bluff and parry. The technologist, on the other hand, needs to be concerned with improving his knowledge of surveillance and countermeasures so that substantive changes in an adversary's arsenal that might drastically upset the balance of power can be detected. In the event of war, of course, the monitoring technology that was used for treaty verification can be turned to targeting enemy weaponry and confirming missile trajectories.

As weapons get smaller and more mobile, they are more easily hidden. For example, nuclear-tipped cruise missiles can be readily deployed on ships, submarines, and in garages, and mobile missiles like the U.S. Pershing II and the Soviet SS-20 can be deployed in irregular patterns that make them difficult to count.

Ideally, those working on monitoring technology would probably do best to make no assumptions concerning arms control treaties themselves, including the likelihood of compliance or violation. In practice, of course, they must respond to the policymakers, who may require a certain monitoring capability—for example, the Vela satellite to verify compliance with the Limited Test Ban Treaty of 1963. But they should not be unduly influenced by fashionable strategies—they must seek new ways to identify and count weapons currently outlawed or possible new weaponry.

With the growing difficulty of effective verification, there is some reason to believe that a mix of remote and on-site techniques may be necessary. Some students of the subject are proposing the imaginative concept of a joint U.S.-Soviet project to study and put in place just such a hybrid verification program. Such a cooperative venture may seem less radical with the passage of time—particularly as other nations, including those disposed to the practice of terrorism, gain access to nuclear weaponry.

—Donald Christiansen

SPECIAL REPORT/VERIFICATION

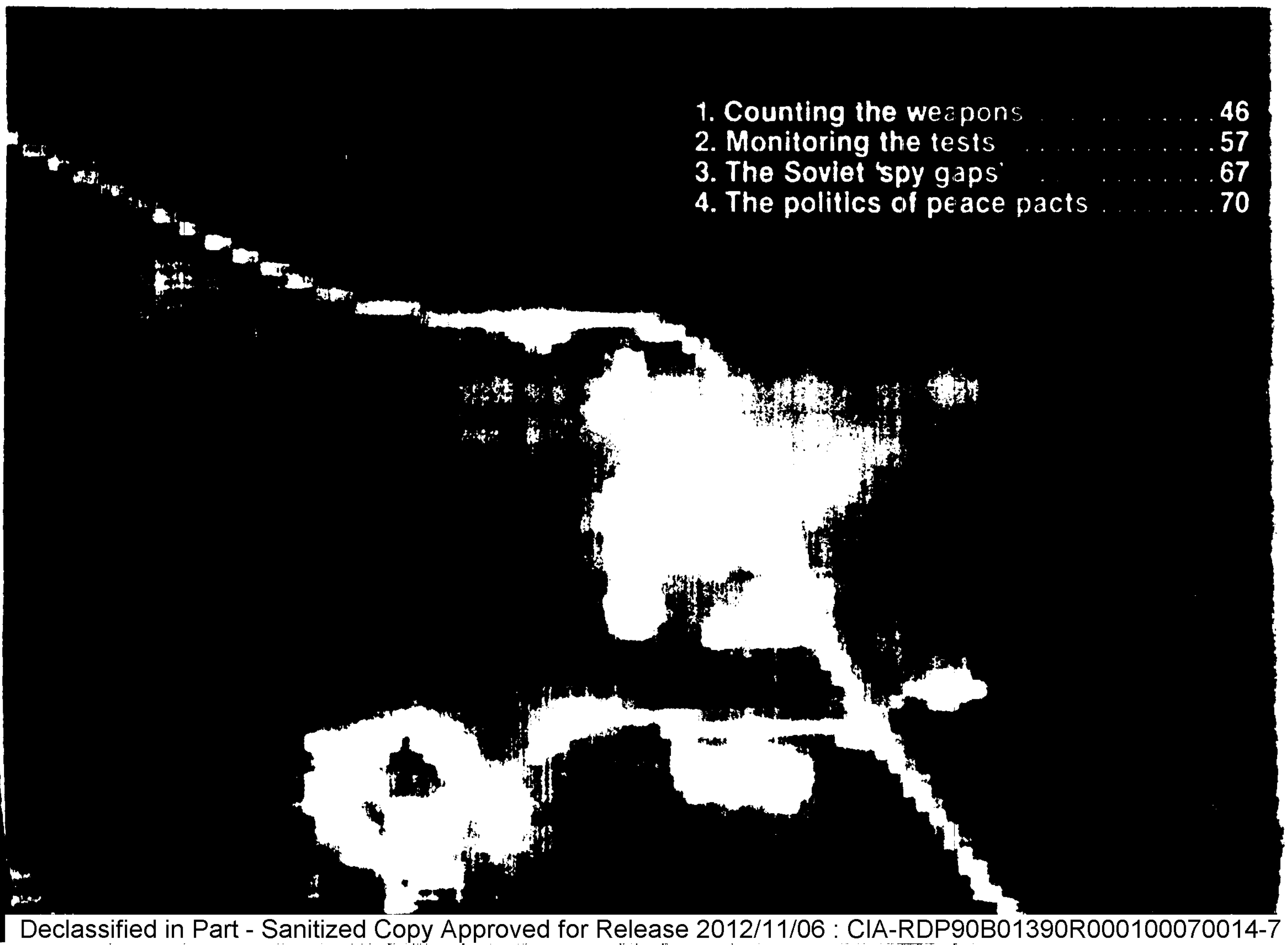
PEACEKEEPING BY TECHNICAL MEANS

Each day U.S. reconnaissance satellites and planes produce hundreds of images of the Soviet Union that must be interpreted. It is an imprecise and complicated process. Is that white blur near the building different from the blur in the last picture? Does that cluster of missile launchers near Plesetsk put the Soviets over the agreed limit?

Listening devices intercept more data. During the 20 or so test flights of a new strategic ballistic missile, data is collected that fills thousands of reels of magnetic tape. These must be processed, analyzed, and correlated to determine the characteristics of the new missiles—an effort requiring tens of thousands of manhours, according to one account by former U.S. Defense Secretary Harold Brown. The result is a mixed pot of technical data varying in quality. Analysts boil this down into timely intelligence assessments, and policymakers then compare the reports with written treaty. This leads to interpretations that are occasionally straightforward but oftentimes fraught with ambiguities.

John A. Adam   Associate Editor

Such is the stuff of treaty verification. Front-page news accounts frequently allude to it. The Reagan administration signals its intent to scuttle the 1979 SALT II arms pact, saying through Secretary of State George P. Shultz: "We want to get away from the technicalities, so to speak, of what this unratified and increasingly obsolete treaty may or may not have called for." The Soviet leader, General Secretary Mikhail S. Gorbachev, puts forth a proposal—some critics say a public relations ploy—to abolish nuclear weapons by the year 2000 and says that "the Soviet Union has



no objection to any verification procedures." Meanwhile, harried U.S. and Soviet arms negotiators in Geneva are reported to be deadlocked about the "verifiability" of new accords. Despite all the media coverage, however, information on the actual verification issues and abilities appears to be sketchy.

At present the United States and the Soviet Union scrutinize each other through "national technical means"—an assortment of sensors scattered throughout the earth and beyond, from the mucky ocean bottom to the high orbits of space. The global intelligence system includes satellites that take still photographs or movies of enemy weaponry, electronic ferrets that intercept telemetry and communications, seismic networks that take the pulse of underground nuclear explosions, and radars on the ground and at sea that follow the flight of test missiles. Unlike cloak-and-dagger human espionage, this technical monitoring is legal, sanctified by the United States and the Soviet Union beginning with the 1972 Strategic Arms Limitations Talks (SALT I) agreement.

Such nonintrusive observation, most experts agree, has produced a stabilizing effect on superpower politics. Each side knows what the other is doing. This helps reduce surprises and damp exaggerations of the worst fears about the opponent. The remote sensing technology also has made nuclear arms agreements like SALT I and II and the Limited Test Ban Treaty politically palatable, because each side can verify independently that the other is not cheating.

But today verification and arms control are teetering upon another threshold. Gone are the days when "spy" satellites had the sole task of monitoring easily observable missile silos, antiballistic missile radars, or strategic submarines equipped with nuclear missiles. These modern war instruments take years to build and are so immense that construction must be completed outside any structure that could cover it. Now, however, a new line of offensive strategic weaponry is proliferating: the United States and the Soviets are deploying mobile missiles and ever-smaller cruise missiles that can be sheltered in garages. Intelligence and arms control specialists are wrangling with questions like these: Should mobile and concealable weaponry be limited or allowed to multiply? Should certain bomb or missile testing be halted? Could such test bans be confidently monitored to halt some developments in weaponry?

Many experts agree with Ralph Earle II, former director of the U.S. Arms Control and Disarmament Agency, who said, "If we want to go beyond the existing limitations treaties, I certainly think that cooperative measures that include, but are not limited to, on-site inspections are needed."

In the past, arms control agreements benefited directly from improvements in remote surveillance. The Vela Hotel satellite, designed by the U.S. Air Force and two national laboratories to detect sudden light flashes and gamma-ray bursts from above-ground nuclear explosions, made the Limited Test Ban Treaty possible. The first two Vela satellites, built by TRW Inc., were sent aloft Oct. 17, 1963—seven days after the treaty between the United States, the United Kingdom, and the Soviet Union went into effect.

Another prime example is the SALT I agreement, which limited antiballistic missile systems. The United States was able to sign this treaty in May 1972 partly because it was confident that photoreconnaissance satellites finally had resolution that was sharp enough to monitor Soviet compliance. The top-secret U.S. National Reconnaissance Office had launched its new Big Bird satellite on June 15, 1971. Built by the Lockheed Corp., it was the first spy satellite capable of both wide-area searching and close inspection; its resolution was reportedly 20 centimeters from an orbit 145 kilometers high. The capability of earlier U.S. spy satellites, like the KH-8, first lofted in 1966, had sown the idea for the negotiations, according to a former official at the U.S. Central Intelligence Agency's National Photographic Interpretation Center.

The coarse 30-meter resolution offered by civilian Landsat imagery was adequate to detect deployment of Soviet mobile SS-20 missiles aimed toward Western Europe. Image interpreters at West Germany's Ocean Earth Corp. concluded that five SS-20 bases and at least one new SS-25 base are deployed among the pine forests north of Kirov. A telltale sign of one complex at left is the cul de sac. The images were made in August 1985.

Ocean Earth Corp Sygma

Implicit in both the Limited Test Ban and SALT I treaties was the common understanding that the arms race was costly and could be limited without compromising national security. Today, however, the issues are not as simple. The more complex relationship between verification, military intelligence, and national security is typified by the cruise missile problem. Sayre Stevens, a former CIA deputy director of intelligence with more than 20 years of experience observing Soviet weaponry, described the trend. "There is high interest," he said, "in both the United States and the Soviet Union to protect likely targets through dispersal, concealment, and other techniques that make targeting—and verification—difficult."

To limit weaponry, it must be "countable," and therefore in most cases today it must also be targetable. But military leaders favor strategic forces that are hard to detect, like cruise missiles and submarines, because such weaponry cannot be easily destroyed in a preemptive strike.

A retired U.S. admiral, Stansfield Turner, who directed the CIA from 1977 to 1981, told *Spectrum*: "Cruise missiles are good in the strategic environment. They don't threaten anybody with a first strike. They are very likely untargetable, so they leave you comfortable if you have them. They don't make the other fellow nervous. So why do we worry about counting them? It's because arms controllers have gotten out of control." He added that because they are not a good first-strike weapon, "I don't really care if the Soviets have 10 000 cruise missiles."

But though the argument can be made that the current generation of relatively slow-flying cruise missiles are less threatening than accurate hypersonic ICBMs, many would take issue with the idea that small nuclear missiles should be allowed to proliferate without bounds. Similar arguments can be heard for antisatellite weaponry and biological and chemical agents.

Perhaps because of this discord, little concrete progress has been made in arms control since the 1979 SALT II treaty, which adroitly put off the cruise missile problem. Manfred Eimer, assistant director for verification and intelligence at the U.S. Arms Control and Disarmament Agency, said: "We're in desperate need to avail ourselves of technological opportunities. We've learned a lot about how to draft treaties and so on, but independent of that, it is clear things are getting smaller and harder to verify."

Strategic arms controllers face another fundamental problem that is less technical. According to John Steinbruner, director of foreign policy studies at the Brookings Institution, the United States is primarily interested in cutting existing arsenals to alleviate a perceived threat to U.S. ICBM forces and a politically sensitive imbalance of weapons deployed in Europe. By contrast, he argues that the Soviet Union is chiefly concerned with restricting technical improvements that are seen as an emerging threat to itself. Thus the Soviets wish to shackle the U.S. Strategic Defense Initiative and to halt all testing of nuclear explosives.

"With the United States committed to revising the past and the Soviet Union to shaping the future, viable compromise requires arrangements that do both," Steinbruner explained recently in an article in *Foreign Affairs* [Summer 1985 issue]. Such a compromise—quantitative reductions in old weapons and qualitative constraints on new ones—was arguably worked out in SALT II, but appears stalled at present.

Nevertheless, despite the current political mood, the U.S. government still sponsors projects to verify potential arms control accords, like a comprehensive test ban to halt all experimental nuclear blasts. And a half-dozen researchers at U.S. national laboratories are investigating technologies and cooperative techniques under which mobile and cruise missiles might be made

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COUNTING THE WEAPONS

Many top-secret 'eyes in the skies' keep vigil over Soviet weaponry; just how sharp are they?

When a Titan 34D rocket exploded shortly after launching from Vandenberg Air Force Base in southern California in April, the accident sent chills through the U.S. intelligence community. The classified cargo of the rocket was a reconnaissance satellite; it was the second such failure within nine months. Coming on the heels of the U.S. space shuttle Challenger disaster in January, it meant new surveillance satellites would be grounded for months. Worse yet, only one imaging satellite for intelligence was left in orbit.

The debate that followed underscored two fundamental points about the U.S. network of "eyes in the skies": the earth-observing telescopes in space are essential for national security, and the orbital surveillance network appears to be more fragile than it is extensive.

It was not until last year that the Soviet Union maintained an uninterrupted presence of photoreconnaissance satellites in orbit, according to Nicholas L. Johnson, an expert on Soviet space developments and an advisory scientist at Teledyne Brown Engineering, Colorado Springs, Colo. The United States, by contrast, usually relies upon two or three such satellites in space at a time. They generally fly over the poles in an elliptical orbit, from a low of 150 kilometers, where there is still some atmospheric drag, to a high of 530. At typical orbits the same latitude is revisited every hour and a half. But because of the earth's rotation, the longitudinal point moves about 22.5 degrees west each orbit. In other words, if the first pass of the satellite was over Moscow, the next would be about 2500 kilometers to the west, over Prague, Czechoslovakia. Such an orbit affords only intermittent views of many spots on the globe, and even then clouds may be a problem. So imaging resources for intelligence are usually concentrated along a few strategically important paths; many U.S. government bureaucracies jostle over what targets will be closely inspected.

According to one former Defense Department official: "If the Soviets put something up in Sary Shagan [a missile testing and radar site] we see it right away. If they put it out in the boondocks it may be months, years, or longer before we know it is there."

Ralph Earle II, a chief U.S. negotiator at the SALT II talks and former director of the U.S. Arms Control and Disarmament Agency, explained it another way: "Obviously one would like to have three times as many satellites up there as we usually have."

John A. Adam
Associate Editor

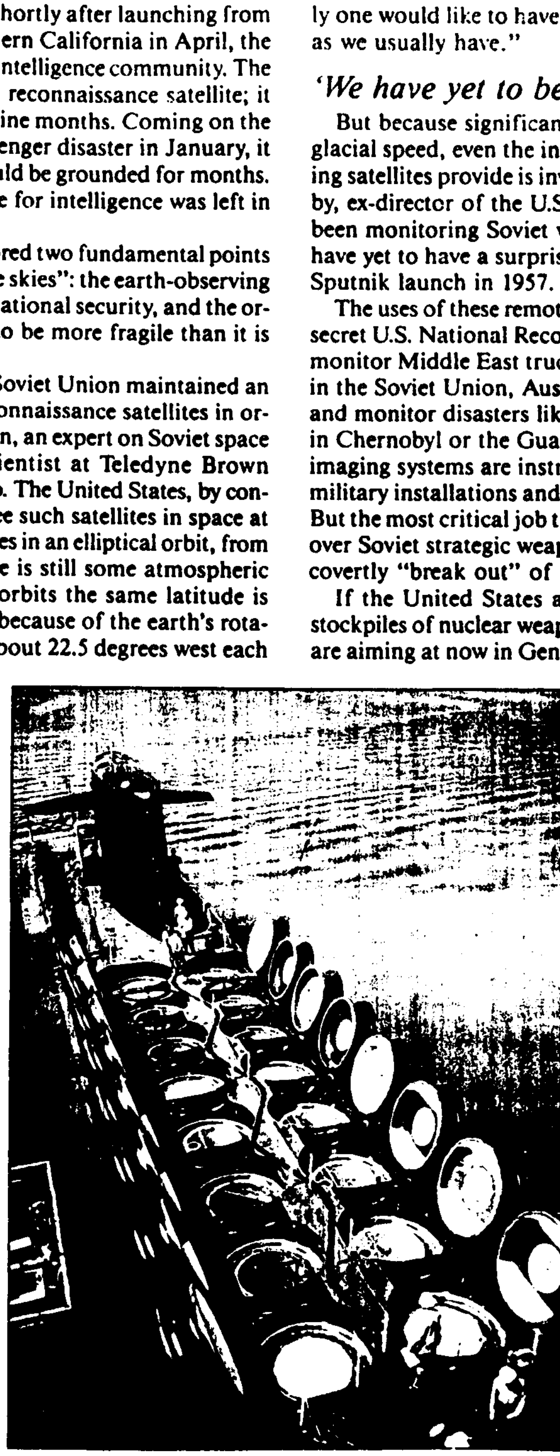
'We have yet to be surprised'

But because significant strategic changes usually occur with glacial speed, even the intermittent coverage that current imaging satellites provide is invaluable. According to William E. Colby, ex-director of the U.S. Central Intelligence Agency, "We've been monitoring Soviet weaponry for the last 30 years and we have yet to have a surprise." The last surprise, he said, was the Sputnik launch in 1957.

The uses of these remote sensing satellites, operated by the top-secret U.S. National Reconnaissance Office, are manifold. They monitor Middle East truce agreements; help predict crop yields in the Soviet Union, Australia, Canada, Argentina, and India; and monitor disasters like the Soviet nuclear reactor explosion in Chernobyl or the Guatemalan earthquake. The space-borne imaging systems are instrumental in targeting Soviet and other military installations and for compiling accurate military maps. But the most critical job the satellites have may be keeping watch over Soviet strategic weaponry to ensure that the USSR cannot covertly "break out" of an arms control treaty.

If the United States and the Soviet Union are to cut their stockpiles of nuclear weaponry by 50 percent—a goal negotiators are aiming at now in Geneva—each side must be extremely confident that the other is not cheating to the extent of achieving a first-strike capability. With smaller strategic stockpiles the counting of enemy weaponry must be more precise, since smaller changes take on greater significance. Is the technology for monitoring these new agreements up to the task, or have developments in concealable, mobile weaponry outstripped monitoring means? And with movable systems like the newly deployed Soviet SS-25, how can the United States be sure it is not "double counting"?

With certain cooperative measures to aid verification, the technical means for monitoring new treaties—whether it be a new satellite sensor or a tamperproof holographic imprint on a mobile missile—seem within reach. In the



U.S. Department of Defense

[1] A U.S. strategic nuclear submarine, the Sam Rayburn, bares its missile launching tubes. It was decommissioned last year to keep the United States in compliance with the SALT II agreement.

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view of Manfred Eimer, assistant director for verification and intelligence at the U.S. Arms Control and Disarmament Agency, "Remote sensing has hardly begun." Indeed, giant strides have yet to be made in visible, infrared, and radar sensors that could make possible a more constant presence in space, giving the United States added confidence to enter into better-quality arms pacts.

A second factor, more mundane but just as important, is that surveillance satellites will soon become cheaper to use due to their ability to be serviced and refueled by space shuttle crews. With operational shuttles, a satellite costing several hundred million dollars will no longer be rendered useless after three months because its film or fuel ran out.

Finally, if more sensors begin collecting information in orbit, the already overwhelming data processing and handling burden will increase enormously. Some advances in parallel computing, however, are making engineers optimistic about processing multispectral and radar images on spacecraft by the early 1990s. Moreover, researchers are examining the use of artificial intelligence to filter the reams of information. [See "The art and science of photointerpretation," p. 52.]

From spy planes to satellites

Since the late 1950s, when the United States flew then-supersecret U-2 reconnaissance missions over the USSR to view Soviet bombers and the world's first intercontinental ballistic missile test site [Fig. 2], the surveillance task has mushroomed. Nuclear arsenals have swelled from hundreds of delivery vehicles in 1960 to several thousand today. And since the early 1970s, a single missile has been able to carry 10 or more nuclear warheads, each independently targetable, so the firepower of one missile could destroy *both* Boston and New York. A more recent trend has been to make "deliverable" warheads easier to conceal; they can now be placed on small mobile launching systems like cruise missiles. Arms controllers thus have a big, diverse pot to deal with. To compound problems, national arsenals are asymmetrical in respect to one another and are in different stages of development.

But concurrent with this evolution of weaponry is the increasing sophistication of monitoring systems. On Aug. 11, 1960, three months after Francis Gary Powers was shot down in a U-2 over the Soviet Union, the United States recovered the first film capsule from the world's first photoreconnaissance satellite, the Central Intelligence Agency's Discoverer.

Space can easily seem so distant and alien that one forgets in fact how close it is. The atmosphere tapers off at around 125 kilometers—or less than the distance from New York to Philadelphia. For spy telescopes in an orbit grazing the earth's atmosphere, that distance is hardly astronomical.

Nevertheless, satellites like Discoverer, flying at five to 10 times the altitude of the U-2, were no match for the spy plane in terms of producing high-quality photographs. "It was looked upon more as an interim measure," recalled Lyman Kirkpatrick, who retired as executive director of the CIA in 1965, after serving with the agency since its founding. Moreover, according to Arthur C. Lundahl, director of the CIA's National Photographic Interpretation Center during 1956-73, the U-2 had covered only a fraction of the Soviet Union. So the center's "database" of high-resolution intelligence photos was deficient. Probably not until the Keyhole 8 (KH-8) satellite made its debut in July 1966 did the United States fully recover from the loss of the U-2 flights, in the opinion of Jeffrey T. Richelson, assistant professor of government at the American University, Washington, D.C. It was also during this time that resolution was reported to be sharp enough once again to consider the possibility of monitoring arms agreements.

(In 1956, when the U-2 first began flying, the technical means were available to monitor strategic weaponry, according to Dino A. Brugioni, at one time the CIA's top image interpreter. In fact, in 1955 President Dwight D. Eisenhower, following an earlier attempt by Franklin D. Roosevelt, proposed an "open skies" arrangement with the USSR. This would allow overflights of one another's territory and an exchange of "complete blu[illegible] our military establishments," in Eisenhower's words. The proposal was rejected by the Soviet Union, no doubt partly for fear that the data would be used for military targeting.)

150-kilometer range no problem

The Keyhole 8 was built chiefly for close-look inspections. A newer satellite, Big Bird, also known as Keyhole 9, had the ability to conduct wide-area searches or close-look inspections. Both these met U.S. intelligence needs for 15 years or more. The last of the Big Bird satellites reportedly was carried atop the Titan rocket that exploded in April. First launched in June 1971, the KH-9 was instrumental in verifying SALT I, the first arms limitation agreement signed by the superpowers. (Negotiations for the treaty began in November 1969 and were concluded in May 1972.) With its reported 20-centimeter resolution, the satellite could readily detect antiballistic launching facilities from 145 kilometers high and determine whether any dubious activities were taking place.

In recent years Big Bird has worked in tandem with the Keyhole 11 reconnaissance satellite built by TRW Inc. The Titan booster that exploded last August was reported to be carrying a KH-11, with an estimated cost of at least $500 million. First launched in December 1976, the KH-11 was a pioneering satellite that could

Defining terms

Charge-coupled device: a light-sensitive semiconductor that stores electrical charges in picture elements (pixels) proportional to the amount of light falling on them; also referred to as CCDs, they are read electronically, substituting for film in some photoreconnaissance satellites.

Human intelligence: the gathering of intelligence by human sources.

Intermediate-range nuclear weapons: nuclear weaponry in Europe and Asia that has a range less than 5500 kilometers, unlike strategic intercontinental ballistic missiles.

Multiple independently targetable reentry vehicle (MIRV): warheads that are carried on a ballistic missile and can be directed at separate targets; SALT II limits a land-based missile to 10 such warheads and a submarine-launched one to 14.

On-site inspection: the use of inspectors or sensors by one country to examine or monitor, at the location, the installations and activities in another country.

Qualitative limitation: restrictions on a weapon system's capability; under SALT II, such qualitative limitations include prohibiting more than one new type of intercontinental strategic missile; limiting a missile's launch weight and throw weight; and restraining the number of warheads a missile may carry.

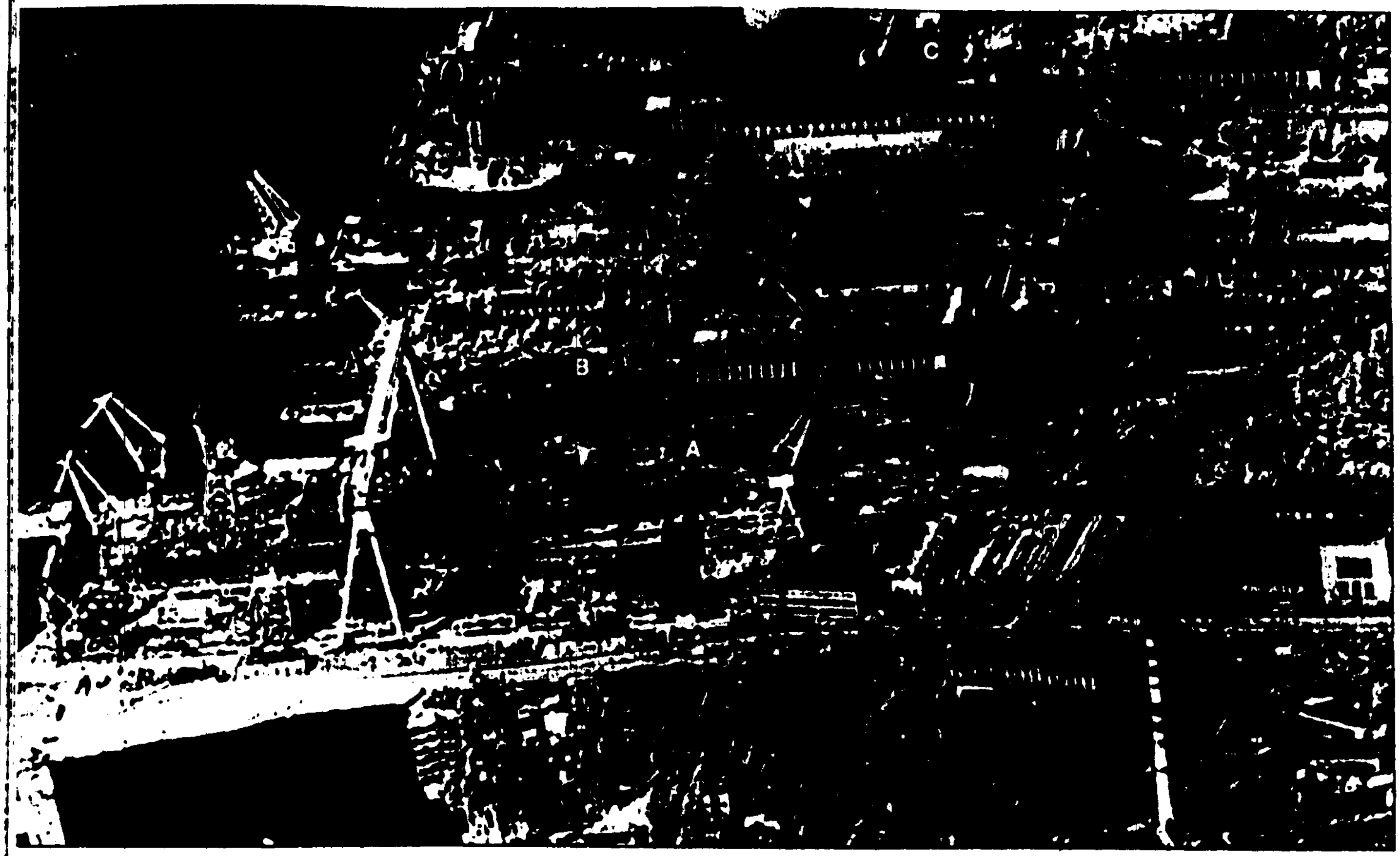
Quantitative limitation: the limits on the number of specific weaponry; the SALT II agreement limited each side's missile launchers but called for no big cuts in strategic forces.

Strategic: a term to denote weaponry or forces capable of directly affecting another nation's fighting ability behind the forward lines of the battle, as distinguished from tactical or theater weapons.

Standing Consultative Commission: a body created under the SALT I agreement by the United States and Soviet Union to privately resolve compliance disputes between them; the group convenes in Geneva twice a year; the U.S. commissioner reports to the U.S. President and has a staff of representatives from a half-dozen government agencies, including some in the intelligence field.

Throw weight: the maximum weight of the warheads, guidance units, and any chaff or decoys that can be delivered by a missile over a particular range and trajectory.

Verification: the technological, analytical, and political process that determines compliance with arms control treaties; effective verification deters violations and is accurate enough to avoid false accusations of other nations; also ensures that any violations are detected soon enough to enable the other country to counter a potential military imbalance.



[2] A computer-enhanced photograph (above), reportedly taken by a U.S. digital-imaging satellite, shows the Soviet Union's first nuclear-powered aircraft carrier under construction at the Nikolayev shipyard on the Black Sea. The carrier, expected to be named the Kremlin *when it becomes operational in 1994, is being built in two sections: the bow (A), 264 meters long, and the stern (B), 73 meters long. The stern of the* Kharkov, *the fourth Kiev-class carrier, appears in the background (C). According to* Jane's Defense Weekly, *this photograph was taken by a KH-11 satellite, which typically operates 240 to 530 kilometers above the earth. Its resolution, slightly better than 1 meter, is probably not the best that can be achieved with current technology; it is comparable in sharpness to a photo of the Soviet Tyuratam test site taken by a U-2 spy plane in 1959 (bottom). Because the rocket booster aperture at the base of the USSR's only launch pad at the time (D) was 15 meters in diameter, U.S. photointerpreters concluded that the Soviets were still using auxiliary rockets to boost their intercontinental ballistic missiles. These were too cumbersome to be deployed en masse, so the assessment allayed fears of a missile gap. The photo was reportedly taken from an altitude of about 20 km. U-2 pilots discovered the site in the Asian desert by following railroad tracks to a dead end.*

U.S. Central Intelligence Agency

relay digital imagery through a communications satellite down to a ground station near Washington, D.C., within minutes. Such "soft copy" images—rather than hard-copy photographs—would then be digitally manipulated in workstations and stored in large computers for later retrieval. In short, the KH-11 introduced an entirely new method of photoreconnaissance and interpretation. Charge-coupled devices (CCDs), invented by AT&T Bell Laboratories in 1970, made the KH-11 breakthrough possible. These semiconductors have the added advantage of a greater dynamic range than film so that the imagery is not over- or underexposed.

Because it is not limited by film capacity, the KH-11 can stay in orbit as long as its fuel lasts—two and a half to three years, depending on the number of adjustments made to the satellite's normal polar orbit. One KH-11 stayed in orbit for three years and two months, according to Anthony Kenden, writing in a recent issue of *Journal of the British Interplanetary Society.*

New satellite to debut when shuttle resumes

The newest addition to the U.S. reconnaissance repertoire, the KH-12, is a craft so big that it cannot be hurtled into space by the Titan 34D. It reportedly will render both Big Bird and the KH-11 obsolete; its resolution of objects on earth may be less than 10 centimeters. Only the space shuttle can lift this four-story-high

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satellite into space, and the job will likely draw on its maximum lift capacity. The KH-12 is scheduled to be one of the first customers when the orbiter resumes flying. (The Air Force is also building a Titan 34D7 rocket, projected to be ready by 1988, that could lift shuttle payloads the size of the Keyhole 12.)

Besides having all the attributes of its predecessor, according to Richelson, the new satellite can see in the dark by using thermal infrared sensors. A further advantage is that it can be serviced and refueled in orbit by the space shuttle.

Because the KH-12 program is highly secret, a new civilian project, the National Aeronautics and Space Administration's Hubble Space Telescope, provides the best example for estimating the level of today's space surveillance technology. This $1.2-billion instrument, designed solely for astronomical observation, is as big as a railroad boxcar and is expected to last 15 years in space with in-orbit servicing. John Pike, associate director for space policy at the Federation of American Scientists in Washington, D.C., called the space telescope an unclassified version of the KH-12. Because the KH-12, like the telescope, must fit in the shuttle cargo bay, it probably has no larger than the 2.4-meter primary optics of the space telescope.

Originally the space telescope was to use a 3-meter-diameter primary mirror, according to Bertram R. Bulkin, the space telescope program manager at Lockheed Missiles & Space Co., Sunnyvale, Calif. With 3-meter optics, scientists could have peered out to 18 billion light-years, where astronomers believe the edge of the universe lies. But because 2.4-meter optics were "more manageable," the Lockheed-program manager said, they had to settle for the scientifically less-appealing 14 million light-years. He added that the hardware needed to grind the smaller mirror was "more adaptable."

Lockheed Missiles & Space Co., reportedly the builder of both the KH-12 and the Big Bird reconnaissance satellites, is responsible for the systems engineering of the space telescope. On its 1-square-mile Sunnyvale complex, in what the company calls the largest clean room in the United States, the 13-meter-long telescope was tested last spring.

The 11 250-kilogram telescope will be close to the maximum load of the shuttle. Only the new Atlantis orbiter will be able to hoist it into space, according to Bulkin and a NASA spokesman. The Titan 34D rocket can boost loads as great as 13 600 kg into low earth orbit, but its cargo bay is not large enough for the telescope, which is so big that it must be shipped from California to the launching pad at Cape Canaveral, Fla., by ocean freighter through the Panama Canal.

"I think anything above a 2.4-meter telescope would probably end up by being a segmented telescope that might be part of the space station," Bulkin said. "I don't see them building anything bigger than this one for shuttle launching."

Bulkin explained broadly how the telescope works. By extension it may help explain the basic concepts behind the latest secret satellite. Light enters the front end of the orbiting Cassegrain-type telescope and is reflected from the primary mirror to the secondary mirror 4.5 meters away. The light is then reflected back through a hole in the center of the primary mirror to a focal plane, where the apertures of five scientific instruments are located. Any two instruments can be used to view the light simultaneously and transfer the images to CCDs or cathode-ray tubes. Images are then recorded on tape or transmitted through a tracking and data relay satellite to earth for processing.

Because of the extreme sensitivity needed to gather faint starlight, the NASA space telescope would be blinded if directed toward earth. But if the telescope were designed to be less sensitive and turned toward the globe from an orbit equivalent to that of the KH-11 reconnaissance satellite, a simple calculation shows that its theoretical ground resolution would be 7.16 cm, or just under 3 inches. [See "A physicist's back-of-the-envelope," right.]

The calculations are based on the telescope's existing optical system and its wide-field and planetary camera, which uses eight arrays of charge-coupled devices for near-instantaneous imaging. Each array is composed of 800 by 800 picture elements; each pixel is 15 microns across. The effective focal length of the Perkin-Elmer optical system is 57.6 meters. Officials at Lockheed added that the designers of the space telescope, on which optical assembly began in the mid-1970s, made use of existing technologies rather than pushing the state of the art.

This estimate of theoretical resolution corresponds to what several knowledgeable sources have told *Spectrum*: actual resolution on current U.S. reconnaissance satellites is sharp, but not capable enough—even under the best platform stability and atmospheric conditions—to distinguish whether a man sitting in Red Square is reading *Pravda* or *Izvestia*. The bold front-page logos of the two Soviet newspapers are slightly smaller than the numbers on a typical auto license plate [Fig. 3]. This also does not conflict with what has been publicly stated about resolution capabilities. Former CIA director Colby told a Senate committee in 1979: "You can see the tanks, you see the artillery, but you may not quite see the insignia on the fellow's uniform."

Such optical acuity, however, is good enough to precisely identify components of nuclear weaponry and confidently describe missile sites and aircraft. Moreover, if absolutely desired, resolution can sometimes be moved closer to its theoretical capability after an image is received. One way is to compensate for known sensor deficiencies; another is to combine several shots of the same scene digitally. [See "The art and science of photo interpretation," p. 52.]

Despite the impressive capability of current telescopes in space, ways to increase resolution of optical telescopes have by no means ground to a halt. NASA's Marshall Space Flight Center and Perkin-Elmer Corp., Danbury, Conn., are studying ways to increase the resolution by a factor of 10 or more for the next generation of astronomical space telescopes. Plans call for building a telescope with an effective primary mirror of 25 meters or constructing a two-dimensional phased array of telescopes. Allen Wissinger, the program's manager at Perkin-Elmer, said both approaches depend on a manned station in space and neither will be realized until the year 2005 at the earliest. The company expects to conduct some optical interferometry experiments and orbital assembly techniques on a shuttle experiment in the early 1990s. A geosynchronous system is being considered for the 2030 time

A PHYSICIST'S BACK-OF-THE-ENVELOPE

What would ground resolution of orbiting space telescope be?

$$\text{Resolution} = \left(\frac{\text{Altitude of sat}}{\text{Focal length}}\right) \times \text{dia. of pixel}$$

Given:

Typical perigee of KH-11 spy satellite:
275 km = 27 500 000 cm

Focal length of space telescope:
57.6 m = 5760 cm

Pixel size of telescope's planetary camera:
$15 \text{ microns} \times \frac{10^{-4}\text{ cm}}{\text{micron}} = 0.0015 \text{ cm}$

Then:
$$R = \left(\frac{27\,500\,000 \text{ cm}}{5760 \text{ cm}}\right) 0.0015 \text{ cm}$$

Ground resolution = 7.16 cm

frame, Wissinger added.

For earth-observing systems, atmospheric distortion restricts resolution to a few centimeters no matter how high telescopes are positioned in space. So the allure of such interferometric telescopes for treaty verification probably has less to do with increasing resolution from low earth orbit than it does with using systems in geosynchronous or Molniya orbits of 20 000 to 40 000 km. One array of cameras could then furnish full- or nearly full-time coverage of a large area. "Although systems of this type are overwhelming to contemplate, they are probably feasible," said J. Richard Vyce, director of advanced program development at Litton/Itek Optical Systems, Lexington, Mass.

Just as important as adequate resolution is proper and timely coverage of areas. A catalog of imagery to detect changes over time in each swatch of Soviet territory is crucial. "If you have repeated coverage of a place you can tell a great deal not only of the changes," said ex-CIA official Lundahl, "but also of the very slippery subject of intention.

"It's like having a movie but the frames are weeks and months apart," he added.

Infrared sensors view 'hidden' sites

Since the early 1960s U.S. surveillance satellites have used multispectral infrared sensors for a number of tasks that confound visible light systems—from observing surface deformations caused by underground nuclear explosions to distinguishing camouflage from natural vegetation. Infrared sensors can also be used to detect underground missile silo complexes, which are warmer than their immediate surroundings.

The KH-12 satellite will be the first space platform with sufficient resolution and sensitivity to make use of thermal infrared imaging, enabling it to see in the dark, according to American University's Richelson. Some infrared wavelengths rapidly degrade when passing through the atmosphere. The two "windows" that have proved valuable for such sensing from space are the near-infrared bands, which rely on reflected solar energy, and the thermal infrared, which senses self-emissions.

Such night-sensing ability may seem less applicable to arms verification tasks because strategic changes occur over a period of months and years rather than overnight. But it could prove useful for monitoring Soviet facilities in the north, like the test sites at Plesetsk and Nenoska, during the prolonged nights of the arctic winter.

The newest of the civilian remote sensing platforms, the French satellite called Spot, and a new type of multispectral scanner at the Jet Propulsion Laboratory, in Pasadena, Calif., are the best available examples of the latest techniques. What distinguishes the Spot satellite from the U.S. Landsat series is not so much its increased spatial resolution—nominally 10 meters, compared with Landsat's 30—but the pointable design of its camera. Unlike Landsat, it does not have to peer straight down. Instead the French satellite can tilt its mirrors 30 degrees to see any site within a 950-kilometer swath, with some degradation of resolution. Thus Spot (for *systeme probatoire d'observation de la terre*) can view the same area every 2.5 days, compared with Landsat's 16.

With this technique, called off-nadir viewing, the same object is viewed at different angles, which greatly aids photo-interpretation for arms verification. The French plan to build a military version of Spot, called Helios, with higher resolution by the early 1990s.

Even the current Landsat, whose spatial resolution was limited by the Pentagon, produces images of strategic intelligence value. For example, a West German company, the Ocean Earth Corp., has identified Soviet SS-20 missile bases by using Landsat imagery [see photo, p. 42] and can distinguish bases under construction. The location of the bases was subsequently confirmed by Western military officials, according to Ingo Gunther, an interpreter at Ocean Earth Corp. Japan has reportedly purchased the commercially available Landsat images to monitor Soviet movements on Sakhalin Island.

For arms verification, fine spatial, rather than spectral, resolution is usually of paramount concern. But, according to Kosta Tsipis, a verification expert and physicist at the Massachusetts Institute of Technology, sensors with fine spectral resolution might help characterize gaseous emissions of Soviet factories to deduce their operations or to monitor the production of potential chemical or biological weaponry. This might be done, he explained, with infrared spectroscopy, in which a portion of the infrared spectrum is divided into hundreds of narrow bands producing distinct signatures of materials based on how they emit or reflect energy according to their chemical composition. The same technique might be employed, he states in the 1986 book *Arms Control Verification: The Technologies that Make it Possible*, to remotely verify a ban on the production of nuclear materials. For instance, activity in plutonium- and tritium-producing reactors and plants could be monitored from space.

Imaging spectrometers have already been tested in aircraft. One designed at NASA's Jet Propulsion Laboratory uses a scanner and a line array of detectors to image a 550-pixel swath in 224 contiguous spectral bands in the visible and near-infrared region. Thus each pixel simultaneously acquires images in each of the 10-nanometer-wide bands. The result, according to Gregg Vane, head of JPL's imaging spectrometry program, is that each pixel has a continuous spectrum "print" that can be used to precisely diagnose surface features.

In Vane's opinion, Landsat "grossly undersamples the spectrum." Its multispectral scanner and thematic mapper have spectral bandwidths of 100 to 200 nanometers. Because many interesting spectral features are typically 20 to 40 nanometers wide, they cannot be observed by sensors on Landsat—or on Spot.

The JPL spectrometer, using a line array scanner, is scheduled to be flown on a NASA U-2 plane this year. For satellite-based imaging, a two-dimensional array is required to combine high spatial and spectral resolution. One is being built at JPL for flight on the shuttle in 1991; a more advanced version is planned for flight on a space station in the mid-1990s.

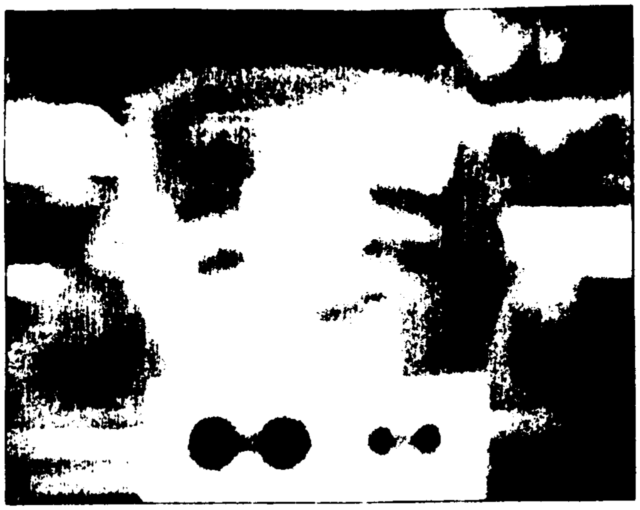
While the 224-band JPL spectrometer can distinguish between different oxidation states of atoms in surface features, it could probably not characterize gaseous emissions directly, Vane said. By observing effects of emissions on vegetation, such a system might call attention to a factory or other area of concern. A nonimaging radiometer might then take Fourier transform spectroscopy measurements, an astronomy technique that can distinguish spectral features within at least 1 nanometer. However, use of such a system on a spacecraft is years away because of the fragility and large size of the instruments, according to Robert J. Bell, a professor of physics at the University of Missouri in Rolla and a consultant for the U.S. Naval Research Laboratories.

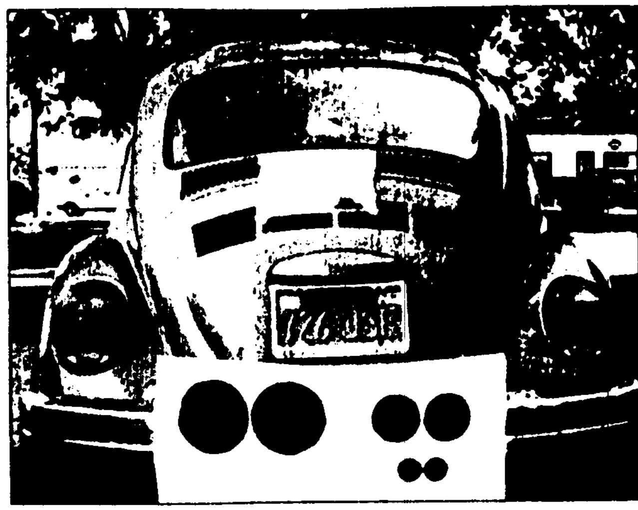
Penetrating clouds with synthetic-aperture radar

Important parts of the Soviet arsenal—particularly in Eastern Europe, where hundreds of mobile Soviet SS-20 intermediate-range nuclear missiles are deployed and where new SS-25 sites are being constructed—are often hidden by cloud cover to both optical and infrared satellite sensors. One solution is radar, which transmits its own electromagnetic energy, generating specific wavelengths to peer through foliage and to penetrate dry soil several meters deep.

At present, according to a U.S. Air Force source, the United States does not use any radar satellites for strategic reconnaissance—although at least one satellite is under development for a launching within the next few years. The Soviets orbit a radar satellite for ocean reconnaissance, dubbed the Rorsat by the U.S. Defense Department. The resolution of its radar, about 40 meters, is adequate for tracking ship movements but too poor for checking arms pacts, according to Stephen M. Meyer, an expert on the Soviet military and associate professor at MIT's Center for International Studies.

For its radar reconnaissance the United States relies on the SR-71 Blackbird spy plane and the stalwart U-2. Each of these





David Hafemeister/Bulletin of the Atomic Scientists

[3] A hand-held 35-mm camera with an extra lens was used to simulate a resolution of about 3 inches, or less than 8 centimeters, in the photo above—a capability said to be within reach of U.S. photoreconnaissance satellites. The black dots on the board propped against the car bumper (right) are 6 inches, 4 inches, and 2 inches in diameter. In the simulation photo, the Izvestia *newspaper logo and the license plate are illegible, but the car can readily be identified as a Volkswagen.*

planes may carry several of more than a half-dozen sensor packages, including infrared spectrometers, optical cameras for oblique photography, and side-looking radar. In operation since 1966, the Blackbird flies as fast as 3500 km per hour at 25 kilometers high, covering the distance from New York to London in less than 2 hours. The effective range of its side-looking radar is estimated to be about 100 km, according to Richelson and others, useful for surveillance of Soviet ports but not for inland areas. (The United States no longer flies over Soviet airspace.)

The potential of radar satellite surveillance has been demonstrated by NASA civilian projects like the Seasat and Shuttle Imaging Radar B experiments. The key to each of these systems was the synthetic-aperture radar technique.

This method takes advantage of a satellite's speed to make a small antenna work like one that is kilometers in length. While the radar transmitter emits signals, the antenna gathers return echoes from points on the ground. A computer can selectively combine these echoes, based on time intervals and the Doppler frequency shift of the signal relative to the moving spacecraft. The length of the synthetic antenna is equal to the distance that the satellite moves during the radar's processing interval.

The Seasat, launched in 1978, pioneered these high-resolution developments. From an orbit 800 km high it had a resolution of 25 meters. In the along-track direction it was capable of 6.25-meter resolution. The length of its synthetic antenna was 15 km.

The shuttle imaging radar lofted in 1984 took the Seasat approach a step further. Unlike Seasat, the shuttle's 10.7-by-2.1-meter radar antenna could be moved at different angles, from 15 to 60 degrees. Multiple radar images of a given target were thus obtained during successive orbits, according to Charles Elachi, JPL project scientist of the Shuttle Imaging Radar. After extensive processing the three-dimensional ground images were viewed stereoscopically.

During an interview in March Elachi proudly showed false-color prints of just-processed shuttle radar images of Mount Shasta, in northern California. The succession of frames appeared as if a person circling the base of the mountain had paused every 1000 meters or so to snap a picture of the summit. It was easy to forget the shots were taken from a spacecraft orbiting 225 km high [Fig. 4].

Even with recent developments, though, there is considerable room for improvement in space-based radar for reconnaissance. Multifrequency sampling and processing speed, as well as resolution, are areas for future growth. Because of its longer wavelengths, radar will never have the sharp resolution of optical or infrared systems, but resolutions of less than a meter are obtainable from space satellites for strategic reconnaissance.

Eli Brookner, a consulting scientist at the Raytheon Corp., Wayland, Mass., explained that increasing the frequency of the Seasat radar from 1.27 to 10 gigahertz would yield a theoretical resolution of 0.8 meter. Lengthening the synthetic aperture is another way to increase resolution, but this is limited by the earth's atmosphere and by altitude. A more distant possibility is an array of radar satellites in geosynchronous orbit, where meteorological imaging satellites are placed, for constant surveillance. For finer resolutions, about 40 kilowatts of power would be required for a system capable of 10-meter resolution with a 15-meter-diameter antenna operating at 2.5 GHz, according to Kiyo Tomiyasu, consultant for General Electric's Valley Forge Space Center. Laser radar, another exotic technique, could offer better resolution than microwave radar but is "still very preliminary," in Brookner's words.

A nearer-term advance, which Elachi likened to going from "black and white to color," is the use of multiple frequencies for radar imaging. This would be akin to the multiband Landsat approach in infrared sensing. Each wavelength emitted by a radar transmitter would be reflected according to the composition of the material. Both JPL and the Environmental Research Institute of Michigan, in Ann Arbor, have experimented with aircraft versions of such a multifrequency radar for both civilian and military uses. The first space version is expected to have three different frequencies, according to Elachi, who is leading the effort at JPL. Plans call for the multifrequency radar to be flown aboard the shuttle in 1990.

Data processing a huge problem

Data processing presents a problem for many technical monitoring systems. Consider for instance the U.S. experience with the Shuttle Imaging Radar in 1984. The space-borne radar collected raw data at 46 megabits per second. From this, signals of interest were winnowed from backscatter for each sampled patch, then correlated with other orbital passes over the same patch. The mere 5 hours of data collected took a year to process, Elachi said.

The intelligence agencies are not immune to problems in processing imagery. According to American University's Richelson, the United States planned to develop a system known as KH-X that would have placed enough satellites in orbit to permit daily coverage of every point on earth. But when the immensity of the processing and analysis requirements became evident, the plan was apparently scrapped.

The Landsat program exemplifies the problem faced by the intelligence community. According to Milton Halem, chief of space data and computing at NASA's Goddard Space Flight Center in Greenbelt, Md., a Landsat orbiter operating 24 hours a day generates some 6000 images. A Vax 11780 mainframe computer can process about 10 of these per day. But a massively parallel processor built by the Goodyear Aerospace Corp. and installed at Goddard last year could conceivably process nearly 3000 images if it worked around the clock, according to Halem. The Goodyear system has 16 384 processors and is capable of 6 billion operations per second of eight-bit words or 350 million 32-bit floating-point operations per second, he added. Another parallel processor recently put on the market by Thinking Machines Corp. of Cambridge, Mass., is the Connection Machine, which uses 65 536 processors.

Halem expects that by the early 1990s imaging satellites will be able to process information on board and transmit images in partly compressed form. An image from a synthetic-aperture

THE ART AND SCIENCE OF PHOTOINTERPRETATION

Every morning at dawn an unmarked Government van slips out the gates of the U.S. Central Intelligence Agency headquarters in the wooded suburbs of Langley, Va. It takes less than half an hour to deliver the previous night's intelligence cache to the national security briefing at the White House. Included are dispatches from global hot spots and, usually, stacks of reconnaissance photos.

One recent briefing likely used a series of images showing construction of a Soviet SS-25 mobile missile base in Eastern Europe. It was a high-stakes interpretation. The missiles and the way they were based meant the Soviets were violating both the SALT I and SALT II agreements, according to the Defense Intelligency Agency.

The essential art of reading photos has not changed much since World War II, but the science has. To analyze images like the SS-25 shots, today's interpreters not only draw on such benefits as finer resolution, but they also can call upon a myriad of digital image processing techniques—such as "change detection" and "automatic mensuration"—to aid them.

But while the CIA is renowned for pioneering efforts in collection systems, its record for innovative information processing is questionable. "It's no secret that our sensor capabilities far outstrip our analysis capabilities," said U.S. Air Force Lieutenant Colonel Robert Simpson, who directs the basic research projects on image understanding at the Pentagon's Defense Advanced Research Projects Agency (Darpa). One former DOD official familiar with applications of the latest technology was asked to what extent the intelligence agencies were using high-power workstations, better organized databases, and artificial intelligence. "It's only leaking in there slowly," he said, adding, "There's an enormous amount of information and only limited staff."

The CIA has employed computers to spot changes automatically from one image to the next since at least 1983, according to an article by Dino A. Brugioni in *Photogrammetric and Remote Sensing*. A CIA photointerpreter from 1948 to 1982, Brugioni still consults for the CIA and the Defense Intelligence Agency.

But the machines are not that useful, even for culling interesting from uninteresting images, Brugioni told *Spectrum*. "In practice, it's not worth a damn," he said. "If I'm monitoring a treaty, you can bet your bottom line that I'm not going to let a machine take my place."

The present level of change-detection systems, for instance, might single out identical objects in two images taken at different times of day simply because the length or darkness of the shadows differed, Simpson said. Current research aims to develop systems that can distinguish between useful and superfluous alterations. "All changes are not interesting," he explained. "If someone paints a building, that's not really something you want to get excited about."

To spot a change automatically, two images must be "registered"—that is, corresponding patches (of, say, 10 by 10 pixels) between the two shots need to be matched. This in itself is a "nontrivial task," according to Simpson, because the sensing platform invariably has changed location slightly between the two pictures; moreover, weather, seasonal, and lighting variations compound problems. High-level change-detection research currently being carried out by such institutions as Stanford, Carnegie-Mellon, and the University of Maryland applies sets of rules in the programs so that only functional variations between different images are highlighted.

Work is also under way to count and identify submarines and bombers automatically from satellite imagery. Under a contract with Darpa, General Motors' Hughes Aircraft division is to deliver a prototype system to "a user facility in the Washington area" by late 1988, according to David Nicholson, the project's manager at Darpa. He indicated the customer is in the intelligence field.

"We're not trying to replace the human, just offload some of his more mundane tasks," Nicholson explained. The artificial-intelligence project at Hughes seeks to keep track of activity at Soviet seaports and airports automatically. Rather than just detect changes, the Hughes system will distinguish various jets, planes, and helicopters on airfields, he said. Using knowledge gained from past observations of the site, the computer is to alert operators of any significant changes in the port's activity. Programs will be model-based, he added, so the software will not search streets or piers for submarines.

The project will make use of two new parallel processing computers—called the Butterfly and the Warp—from the agency's heralded Strategic Computing Program. The goal is to make the system run in real time or near to it "so the intelligence community will have reason to believe in the technology," Nicholson explained. An initial Darpa project completed with Hughes in 1985 used a Vax mainframe computer and relatively uncluttered images. "To do one submarine and one pier took days of processing time," Nicholson said. Although the new system is designed primarily for strategic indication and warning assessments, more refined future systems might be useful for treaty verification.

But it seems doubtful that machines will soon master the nuances needed for photointerpretation. CIA interpreters not only know the tricks of examining photos, they also are versed in the specific industry or weaponry and the culture of the area they are examining. For instance, oxen yoked to water pumps in Southeast Asia often resemble antiaircraft artillery when viewed from aerial or space shots, said Arthur C. Lundahl, former director of the CIA's National Photographic Interpretation Center.

Resolution required for interpretation tasks, meters

Object	Detection	Recognition	Precise identification	Description	Technical intelligence
Missile sites*	3	1.5	0.6	0.30	0.08
Radar	3	0.9	0.3	0.15	0.04
Aircraft	4.5	1.5	0.9	0.15	0.03
Nuclear weapons components	2.4	1.5	0.3	0.03	0.01
Surfaced submarines	30.5	6	1.5	0.9	0.03
Command headquarters	3	1.5	0.9	0.15	0.03
Vehicles	1.5	0.6	0.3	0.05	0.03

*Surface-to-surface and ground-to-surface missiles

Sources: "Crisis Management Satellite," Program in Science and Technology for International Security, MIT Report No 3, 1978, and *Verification: How much is enough?*, Stockholm International Peace Research Institute 1985 radar "could be knocked out in 30 seconds," he said. Others have noted that for military intelligence, these images could be sent directly to ships and field command centers in almost real time to track ship and artillery movements. There may thus be an incentive aside from arms treaty verification to orbit a radar in space.

Large-scale concealment doubted by experts

Even though new space-borne sensors may be able to see in the dark and peer through clouds with ever better resolution to scrutinize Soviet weaponry, remote surveillance has its limitations. Any simple brick shelter, for instance, can hide a cruise missile from the most capable eye in the sky.

Fortunately the trend in arms limitation agreements over the last 25 years has been to make monitoring easier. This is especially apparent in SALT II. Both sides agreed not to obstruct verification by national technical means, such as blinding a space-based sensor with a laser. They also agreed to elaborate dismantling procedures in which decommissioned submarines and dismantled

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He recalled that during the Vietnam War, one photointerpreter detected four times as many camouflaged surface-to-air missiles as his peers. The only explanation Lundahl could offer was that he was highly experienced and had great intuition, so that "he thought like an antiaircraft missile site selector."

Playing digitally to increase resolution

After an interesting object in a photo has been identified, several digital image-processing techniques can be used to restore or enhance the picture. "The way you emphasize some things is by suppressing others," explained James L. Anderson, a member of the technical staff at the Jet Propulsion Laboratory's image-processing section. The twin pillars of image processing—spatial filtering and contrast enhancement—can be used to restore blurred pictures, to "warp" images so that various angles of a structure can be examined, or to embellish details in photos. [See *Spectrum* articles "From Data to Image to Action," December 1985, pp. 45–52, and "Digital Image Processing," April 1979, pp. 38–49.] Similarly, Brugioni noted, shots of the same structure taken at different angles yield data that can be modeled in three dimensions, much like images in computer-aided design.

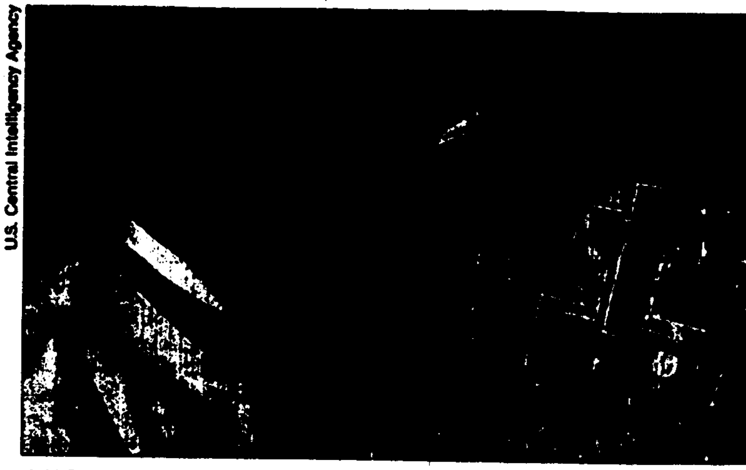
Digital image interpretation equipment makes it possible to zoom in on a particular detail, to restore and enhance the image, to write notes on the screen according to the interpretation, and finally to print a hard copy of the image. Photogrammetric software can calculate precise measurements, adjust for sensor deficiencies, and determine position coordinates of the object under surveillance—an especially arduous task with slant photography or side-looking radar imagery. Such equipment is described in *Airborne Reconnaissance IX*, the proceedings of a 1985 conference of the Society of Photo-Optical Instrumentation Engineers, headquartered in Bellevue, Wash.

Image resolution can be improved by two techniques, according to Anderson. One is to compensate for known instrument deficiencies and atmospheric characteristics by conducting tests to differentiate between the proved and theoretically achievable resolution. The difference can then be compensated for using special algorithms, the JPL researcher said. But there is a risk of introducing "artifacts" into the image—obviously not desirable for planetary exploration or treaty verification.

Another approach, Anderson said, is to combine multiple images of a scene and "register them very carefully" on a computer. Overlaying the shots compensates for deficiencies in the sensor, whether it be a pixel on a charge-coupled device or a clump in a grain of film. "You can add these things up, and if you work really hard you can get up to a factor of two improvement in resolution," he explained, no matter how fine the resolution was to begin with.

But Anderson cautioned that although the technique may be useful for selective applications in verification, it is a very expensive and time-consuming process. "Sometimes the factor of two will buy you something very valuable; other times it won't."

Lundahl, the ex-CIA official, offered an example. "If you're looking at an apartment complex, what good does it do to increase the resolution to where you can see the putty peeling around the windowpane? You don't get that much of an additional intelligence message out of it. You can be satisfied with lesser resolution. On the other hand, if you're looking at some new device down there with a whole series of different-shaped klystron tubes sticking out of it, you want to get resolution down into the inch category" [see table].



U.S. Central Intelligency Agency

A U.S. Central Intelligence Agency interpreter examines a projected aerial view of the agency's headquarters in Langley, Va.

Lundahl said the CIA had a "big filing and recall" problem during his tenure from 1956 to 1973. "And I'm sure it's bigger today," he added, with the development of near real-time imaging satellites like the KH-11. "You sometimes had pictures that were mostly cloud-covered but there might be one little section that had a clear view," he said. "So you didn't throw any of that away."

The CIA used to employ a card file system much like a library's except that the cards contained small images. William E. Colby, director of the CIA from 1973 to 1976, said the agency pioneered computer retrieval systems to replace the card filing system, which suffered from a major drawback: "You had [the information] but you didn't know you had it." One source, a former contractor to the intelligence community, spoke of reams of imagery data being stashed in "shoe boxes and broken filing cabinets."

A passage in a CIA monograph published in 1979 describes the computer retrieval system for photographs. Coordinates on the globe are specified, along with a time period; the computer then conducts a search and produces a printout that lists all photographic references on the subject, whether they are classified or not, and identifies which of the scores of warehouses or galleries they are stored in. The angle of the sun is also recorded. According to photointerpreter Brugioni, "In some cases, you might want long shadows for measurement; in others you want very little shadow for greater detail."

An obvious way to condense warehouses of photos to a manageable size is to use compact disks. Lundahl referred to the "mind-boggling" potential of this method, which would make it possible to have "just mountains of information at your fingertips." To what extent the CIA employs this technology is unknown to outsiders. Another Government agency, however, the U.S. Geological Survey, is beginning a prototype CD read-only-memory database with microcomputer search and retrieval.

"There's tons of information of all forms and sizes and shapes," Lundahl said. "The trick is to get the information that you need on a given subject to a given point while it is still a problem on your desk."

—*J.A.A.*

missile silos would be left in the open for at least 90 days. Each side promised to make counting easier by ensuring that cruise-missile-equipped bombers were built with "functionally related observable differences." Finally, both the United States and the Soviet Union agreed not to conceal strategic weaponry limited by the treaty.

Jet Propulsion Laboratory

As experts point out, the United States insists on verifiability of treaties because it does not trust the Soviet Union. During the SALT II debate in the United States, questions like these repeatedly arose: Do such agreements put too much faith in an adversary? Could large-scale cheating in the USSR's closed society be detected before the Soviets gained a military advantage? Some opponents noted wryly that U.S. intelligence had developed a false confidence in its monitoring ability because, by definition, the United States has never detected anything successfully hidden by the Soviets.

In July 1979 Defense Secretary Harold Brown took issue with that view at a hearing before the Senate Foreign Relations Committee. "Throughout our years of monitoring Soviet forces, we have observed no grain elevators being loaded with ICBMs, no SLBM launchers being installed on fishing trawlers," he said. "One theoretical explanation is that the Soviets are doing an extraordinary job of concealment—with absolutely no breaches of security or inadvertent disclosure of what would be a substantial effort. The other, far more plausible interpretation is that Soviet clandestine deployment of strategic forces, if it exists at all, is at such a low level as to be strategically insignificant."

Ex-CIA chief Colby appeared to agree. He told *Spectrum* recently, "I'm not going to say that we know every little thing that happens in the Soviet Union, but what can be concealed is going to be marginal. It's not going to affect our security."

In time of war, large-scale strategic concealment is routine among belligerents. According to Lundahl, "There are lots of little games between the hiders and the finders." One of the more elaborate efforts was undertaken by the United States in World War II. Two aircraft factories in southern California—Lockheed in Burbank and Douglas Aircraft in Santa Monica—were camouflaged in early 1942, for fear of Japanese bombing. Since

Paranoia and Intelligence

Intelligence sources seem especially jittery these days. The U.S. Central Intelligence Agency, the National Security Agency, and the Defense Intelligence Agency all declined to be interviewed for this report through their public affairs offices. The Soviets, too, refused to respond to written questions submitted in March to their embassy in Washington, D.C. Spokesman Yuri N. Subbotin explained over the phone, "We are called information department but unfortunately it doesn't mean we can supply all the information." *Spectrum's* questions were "too specific," he said.

The CIA denied *Spectrum's* Freedom of Information request for several items, one of which was the U-2 photograph that appears on p. 48. It had already appeared in three publications: the French journal *La Recherche*, *Air Force Magazine* (in an article written by a CIA consultant), and *Time*.

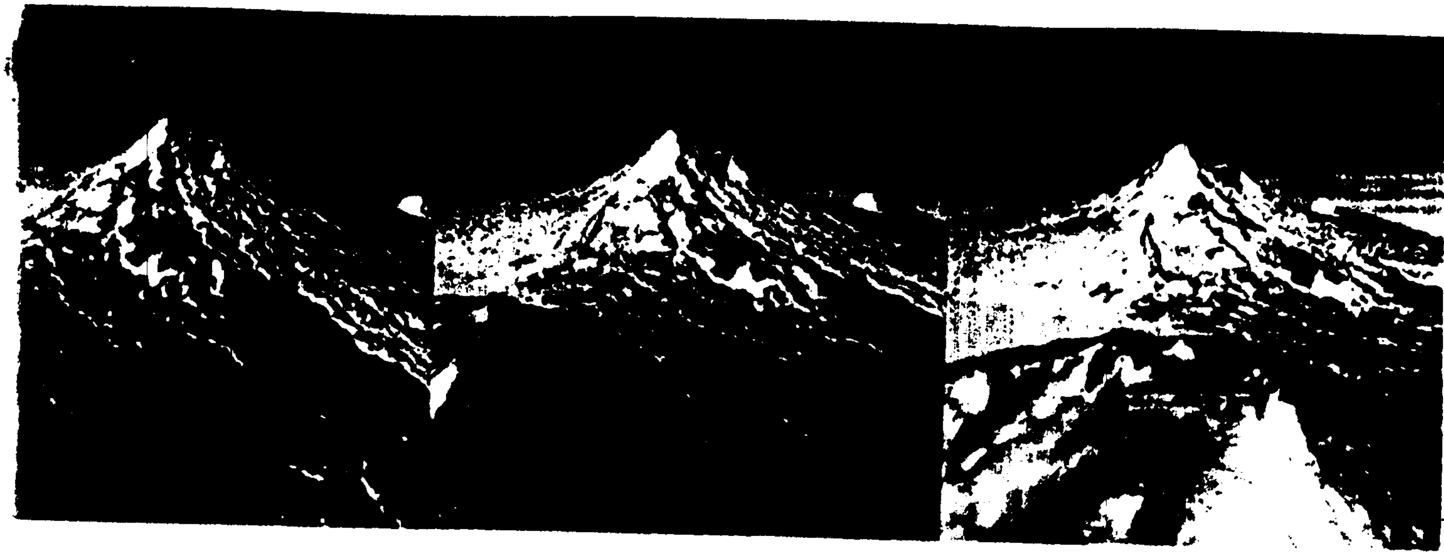
An agency spokesman wrote in a letter, "Although the fact of U-2 overflights of the USSR has been officially acknowledged (e.g. in the context of the Francis Gary Powers incident), information concerning specific intelligence targets has not been released. Therefore the CIA may neither confirm nor deny the existence or nonexistence of records responsive to that portion of your request for a particular U-2 photograph. Such information would be classified for reasons of national security."

The same photo went on public display in May as part of an exhibit of the Smithsonian Institution's National Air and Space Museum. The exhibit's curator, Priscilla Strain, said the CIA had released the U-2 picture along with several others. A copy of the photograph was eventually supplied to *Spectrum* by the agency's public affairs office.

A similar paranoia was also encountered when calling intelligence officers. A reporter placed a call to the Defense Intelligence Agency to contact members of its Scientific Advisory Committee. Under normal circumstances in the Defense Department, the reporter would be politely referred to a public affairs office. Instead the DIA spokesman took the [illegible] "How did you know to call here?" [illegible]," replied the reporter, not wanting to divulge that the number is printed in the unclassified DOD telephone [illegible] did you get this number [illegible] official persisted. [illegible] told this was where the [illegible] Scientific Advisory Committee was." [illegible] my question. How did [illegible] here?" [illegible] don't want to [illegible] were [illegible] classified information [illegible] huh. Well, you [illegible] the DIA official took the reporter's name and telephone number. A few hours later a more relaxed DIA official, executive secretary Lieutenant Colonel H.E. Linton, called back and said he might be able to help out but to check with the public affairs officer first.

In another instance, Ray McCrory, a former CIA official involved in the SALT II talks, was called at his home. McCrory had given an unclassified briefing on verifiability limitations of cruise missiles at the Massachusetts Institute of Technology. "That was rather an embarrassment," he said, recounting how the CIA forbade publication of his paper in a book based on the conference proceedings. Asked if he could elaborate on his unclassified talk, he replied, "I can't give background information [illegible] months or even a year. —J.A.A.

Declassified in Part - Sanitized Copy Approved for Release 2012/11/06 : CIA-RDP90B01390R000100070014-7



both plants were in residential areas, the Army, being in charge of the project, tried to blend the factories and parking lots into the neighborhood. Canvas and scrim, chosen to allow rain to pass through, were stretched over poles to form a tent over the factories. Mock houses, cars, shrubs, and gardens were erected on the tent. Runways and parking lots were also painted, with renderings of houses, baseball diamonds, playgrounds, and tennis courts.

Brugioni, the former CIA photointerpreter, who wrote an article on the concealment in *Air Force Magazine*, contends that photointerpreters would not be foiled by such an effort. Even though mock shadows were painted, the orientation was plausible for only a few minutes each day. Moreover, stereo interpretation would have revealed that the structures had no height. The untested escapade was also time consuming, taking nearly a year to create, and the construction would probably be picked up by satellites if attempted today.

But because the Soviets know well in advance when U.S. monitoring satellites will pass over sensitive areas, they can take steps to conceal strategic programs. For instance, before the digital imaging KH-11 satellite was compromised for $3000 by former CIA employee Wilham Kampiles, the Soviets were unaware it was a reconnaissance satellite. When Big Bird passed over a test center, everything was tucked out of sight. But when the KH-11 passed through the same area, it reportedly detected an aerospace glider—the first clue the United States had that the Soviets were making a craft similar to the U.S. space shuttle.

As for military installations themselves, one Defense Department official in the Carter administration who worked on the SALT II team said concealing a few missiles might be possible but "hiding effective military units is a whole different proposition." They all need support structures and are vulnerable not only to visible and infrared reconnaissance, but to electronic eavesdropping as well.

According to ex-CIA director Colby, the Soviets "certainly believe in camouflage and they try to use it. There are restrictions in the treaty, however—prohibitions against concealment. And several of the issues we've raised with them is whether they are concealing something. If you have a treaty, you can raise that question; if you don't have a treaty, there's really nothing you can do about it."

The United States has traded charges with the Soviets about concealment with regard to treaties. For instance, the Soviets accused the United States of concealing Minuteman silos under construction; the size of the shelters was subsequently reduced.

Accuracy of missile count varies

For either side to be willing to enter into a treaty, it must be confident that it can count the other side's weapons with certainty. The most recent version of *Soviet Military Power*, compiled from

[4] A false-color synthetic-aperture radar image of Mt. Shasta, which gives the perspective of looking up toward the summit, was taken from the space shuttle. The sequence of images is equivalent to 90 degrees of a full 360-degree representation of the mountain. The images are based on two overflights at differing angles of the Shuttle Imaging Radar B.

unclassified reports of the U.S. Defense Intelligence Agency, puts the number of Soviet mobile SS-20 launchers deployed at 441. In 1981 the estimate was a more rounded 250. How good are these estimates?

"Some are accurate to absolute precision," said the former Defense Department official on the SALT II team, citing strategic submarine counting and silo counting as examples. In the case of the SS-20s, the Defense Department assumes that nine launchers are housed in each of the 49 shelters, resulting in 441 missiles. The shelters are relatively easy to find. "You're much more likely to make the mistake of whether there are five or six or nine missiles per installation," the source said.

A more complicated counting problem arises with cruise missiles, because they can be placed on ships or in submarine torpedo tubes. They also can be produced and deployed covertly. Asked if the current monitoring system can keep track of cruise missiles, Colby replied: "It's adequate to measure the degree of military threat we face. It's not necessarily adequate to define each last single cruise missile—that's another question. But a military force that threatens us, I guarantee you we'll see."

He said this even applies to ground- and sea-launched cruises. "They all need bases," he said. "They all need support structures. They all need construction facilities. They all need units that operate them, and all the rest of those things. You then put the bits and pieces together, and you can see if you have a threat."

'Tagging' mobile weaponry for identification

Whether cruise or mobile missiles should be controlled or allowed to proliferate unbounded is a matter of contention. But mere general knowledge of a threat is inadequate for verifying a treaty. Researchers at Lawrence Livermore and Sandia national laboratories are examining "advanced concept" techniques to "tag" concealable mobile weaponry. The challenge is to design a system that permits counting for verification but does not increase the weapon's military vulnerability. So far the techniques have taken only vague form.

Fred Holzer, deputy chief of Livermore's verification program, outlined the constraints. The tags must be tamperproof, not duplicable, and they must in no way interfere with the missile's operation, he explained. Moreover they must be designed so they cannot be used, or even perceived to be usable, as a homing device.

Numerous schemes exist. For new missiles, tags might be installed on the production line. A special mold with an intricate surface pattern has been suggested as a tag; after the required number were produced, Holzer said, the mold would be broken. Another possibility, for new or already deployed weaponry, would be to use a photomicrograph or acoustic hologram of a small patch on the missile, which could be compared with a master file or database of the fiber patterns of "legitimate" missiles. Yet another option might be a microchip tag that could be queried upon inspection.

The basic technologies are now being employed by such auto manufacturers as BMW and Honda. BMW uses a chip containing such information as paint color, desired options, and so on; the chip is queried during assembly. Honda is considering using an intrinsic property of its spare parts, like fiber grains, to assure authenticity.

Not entirely cloak-and-dagger

Formed in 1947 from the Office of Strategic Services, the U.S. Central Intelligence Agency has a wide-ranging mandate. It gathers overseas intelligence from secret agents, funds clandestine work in such countries as Nicaragua and Afghanistan, sponsors conferences at top universities, monitors the worldwide wheat crop, and helps develop classified surveillance and monitoring systems.

The CIA is also a major U.S. player in arms verification and photoreconnaissance and analysis. Unlike the Pentagon's Defense Intelligence Agency, the CIA concerns itself less with tactical and operational activities than with strategic problems, such as analyzing the design of a new Soviet intercontinental ballistic missile. Most of the analysis takes place at the agency's headquarters in Langley, Va., surrounded by 219 acres of woodland. Plans call for the CIA headquarters to double in size by 1987.

The agency also analyzes seismic data collected by the U.S. Air Force and competes with the Defense Intelligence Agency in analysis. The CIA's National Photographic Interpretation Center, at the Washington Navy Yard, serves as the central U.S. facility for image interpretation and repository of intelligence photos.

The CIA pushes the state of the art in intelligence gathering. After developing the U-2 spy plane in the 1950s, for instance, it pioneered the first spy satellite, Discoverer. The U.S. Air Force then made incremental improvements in the 1960s with other film-imaging satellites, like the Samos and Big Bird. It was the CIA in the 1970s that spurred design of the Key Hole 11 real-time digital imaging satellite. The agency was also behind the Rhyolite satellite, which intercepts Soviet communications from geostationary orbit.

Even more surreptitious than the CIA is the National Reconnaissance Office, administered by the CIA and the Defense Department. Though it was established in 1960, it still is not officially acknowledged. Its multibillion-dollar budget exceeds that of the CIA. The office, which plans, builds, and operates the U.S. fleet of reconnaissance satellites, is overseen by a small executive committee headed by the CIA director and the secretary of defense.

—J.A.A.

But according to Roger L. Hagengruber, vice president of systems analysis at Sandia: "The technical means of tagging are not sufficient alone. It's a systems engineering problem, which is, How would you design a system that's negotiable, practical, and doesn't cost half the national debt?"

Effective tagging may have utility beyond verification. For instance, cruise missiles might be tipped with nuclear or nonnuclear explosives. Without tagging, a commander during an ostensibly conventional war would not know whether incoming cruise missiles were nuclear or not. Resolving such an uncertainty might prevent a conventional war from escalating into a nuclear one.

Some arms limitation schemes include operational constraints that aid verification, for instance the restriction of mobile missiles to specific zones, as considered by the Geneva negotiators. Yet another way of determining the presence of missiles is electronic surveillance. "Military forces awaken weeks, months before they can be brought to bear," according to one former director of an agency in the Defense Department. "In that awakening, they give themselves away very clearly and unequivocably." He suggested this might be one method of verifying a ban on intermediate-range nuclear forces, like the mobile SS-20 missiles, in Eastern Europe: mobile missiles rely more heavily on radio communication, rather than more secure land lines, to ensure their mobility.

Sea and space surveillance

Surveillance embraces not only ground and air weaponry but objects in sea and space as well. Submarine construction can be detected by reconnaissance satellites, but to keep track of vessels at sea the United States employs a network of acoustic hydrophones. The sensors, called the Sound Surveillance System, rest along the bottom of the oceans' continental shelves. Though unrelated to any arms agreement, except possibly the Seabed Treaty's ban on deployment of nuclear weapons in the ocean, these sensors would play a critical role in a pact to restrict operations of strategic nuclear submarines in designated zones.

Counting and characterizing objects in outer space is the job of the North American Aerospace Defense Command (Norad). It is not clear to what extent its ground-based sensors could verify that no nuclear weapons were deployed in space, as called for in the 1967 Outer Space Treaty. But its radars can track objects in space as small as an astronaut's glove and keep simultaneous track of more than 5400 objects in orbit today. Based on such factors as orbit and inclination, satellites can be characterized as performing reconnaissance or communications intelligence. It is more difficult, however, to assess whether a Soviet satellite is a civilian or military remote sensing platform.

Like U.S. earth imaging satellites, Norad's latest surveillance system replaces film with digital imagery. Called the ground-based electrooptical deep space surveillance system, it can detect earth-orbiting satellites to 35 500 km. Its 1-meter telescopes can spot objects 10 000 times dimmer than the human eye can see.

One hundred images each minute are converted to digital pulses and fed into a computer to filter out the light from stars. The information from bases in South Korea, Hawaii, and New Mexico (and later from Diego Garcia and Portugal) is sent immediately to the U.S. Space Command in Colorado. The previous telescopes' film had to be processed and manually interpreted, requiring more than an hour of time, according to Norad.

In space, at sea, and on the ground, Soviet strategic weaponry is counted by the United States. From the post–World War II era to the present, "an almost steady and very sharp increase in total knowledge" of the Soviet Union has resulted from advances in remote surveillance means, said ex-CIA director Colby. No one can dispute his claim that the coverage is only going to improve. But if the eyes in the sky are going to be used as more than targeting means and threat assessors, leaders of the superpowers will have to reach some accord. If they do, the monitoring technology, at least for counting mutual reductions in weaponry, will most likely be waiting. ◆

MONITORING THE TESTS

Missile flights and test explosions are watched closely to determine whether an adversary's new weapons might upset the strategic balance

To the naked eye, the tail end of a Soviet missile test high above the Kamchatka Peninsula in northeastern Siberia is almost imperceptible. A cluster of tiny dots of light—the burning nose cones of 10 reentry vehicles—flare briefly as they arch earthward. To the hundreds of millions of dollars' worth of U.S. Defense Department sensors and computers in the region, the same fleeting event is a gold mine of data on the Soviet missile.

Infrared sensors aboard specially modified RC-135 reconnaissance planes record the wavelengths of the light emitted by the glowing nose cones; subsequent analysis will tell U.S. scientists the temperature of the cones and what they were made of. Radars on the planes, on a ship in the Kuril Trench below, and on Shemya Island in the Alaskan Aleutians, determine the speed and trajectory of the vehicles as they reenter the atmosphere. Visible-light sensors and movie cameras on the RC-135 planes record the descent to fill in any gaps that might remain. Even the weather is monitored—a sudden movement of the missile or a temperature fluctuation might be the result of rain, a thermal air current, or a shift in wind direction.

Similarly orchestrated U.S. intelligence maneuvers accompany the earlier phases of Soviet missile launches and the underground tests of nuclear explosives. Nonetheless, despite mounds of data collected, debate continues at the highest levels of the U.S. government about Soviet compliance with arms control treaties.

The disagreement between the Central Intelligence Agency and the Department of Defense concerning the interpretation of seismic recordings of Soviet underground tests is one example. Last Jan. 21 William J. Casey, director of the CIA, agreed to revise the agency's method for estimating the yields of Soviet test blasts. The change shifted previous estimates of yield downward by about 20 percent. As a result, questions have arisen about the previous U.S. assertion that the Soviets have detonated at least 14 test explosions that exceeded the 150-kiloton limit set by the 1974 Threshold Test Ban Treaty. The new estimates of yield appear to put only four tests significantly above the 150-kiloton limit.

The CIA and the Defense Department are also reportedly at odds over the number of warheads carried by the 16-year-old SS-18 missile, known as the RS-20 to the Soviets. It is the staple of the USSR's liquid-fueled intercontinental ballistic missile fleet. The CIA believes that the missile conforms to the SALT II limit of 10 warheads, while the Defense Intelligence Agency is said to contend that the missile can handle 14 warheads, which would violate SALT II. The Defense Department's annual publication *Soviet Military Power* asserts cryptically that the number is "10+."

Glenn Zorpette
Associate Editor

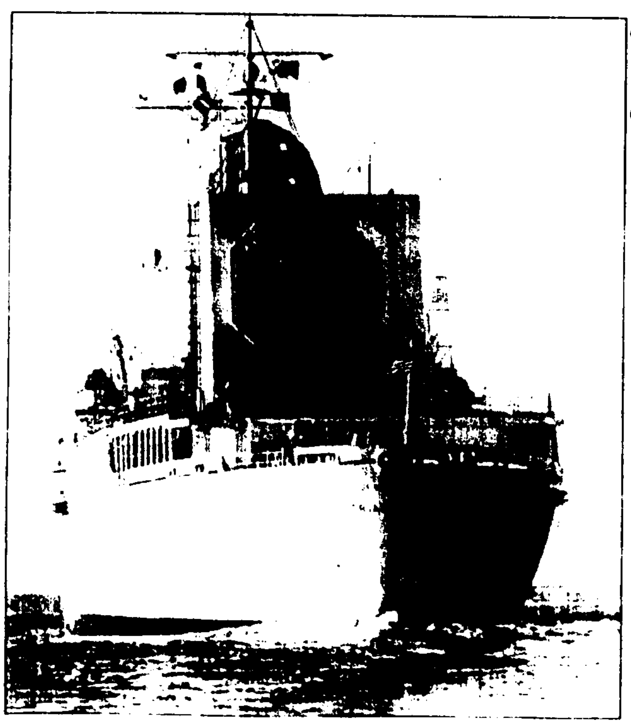
Does dissension like this mean there is something fundamentally wrong with U.S. ability to monitor Soviet weapons tests to determine whether they comply with arms control treaties? "Differences of opinion are natural," said William Colby, who was CIA director from 1973 to 1976. He added that major differences should be aired within the intelligence community to call attention to uncertainties that may exist.

Others note that while the collection of data may be an objective process, the analysis of data certainly is not. "Depending on the assumptions you make and the methodologies you use, there's room for debate," said Jeffrey T. Richelson, an assistant professor of government and public administration at the American University in Washington, D.C. "If you want to make the threat seem as great as possible, you can make one assumption. If you are less nervous, you can make another."

Still others question the importance of the differences altogether. Concerning the competing methods for interpreting seismic records of underground nuclear tests, Manfred Eimer, the assistant director for verification and intelligence at the U.S. Arms Control and Disarmament Agency, said: "The shift that Casey has been talking about for the last two years is trivial. It's strictly a game of politics. It has no meaning."

While uncertainty is not necessarily a bad sign, it can undercut arms control treaties by calling into question the ability to verify compliance. Invitations by the Reagan administration and top Soviet officials to resuscitate the dormant Strategic Arms Reduction Talks (Start) focus attention once again on verification technologies. How much do they tell the United States about Soviet capabilities?

Adding to the urgency, the United States is seeking with the Start talks to reduce the total Soviet strategic ballistic missile throw weight by about 50 percent, while reducing the number of its own warheads by a similar


Raytheon Co.

[1] The USNS Observation Island *monitors the reentry of Soviet test missiles over the Kamchatka Peninsula and the Pacific Ocean.*

factor. With reductions like these, knowledge of weapons capabilities becomes even more critical. With smaller stockpiles, improvements in capability can upset the strategic balance on which peace depends.

Telltale telemetry

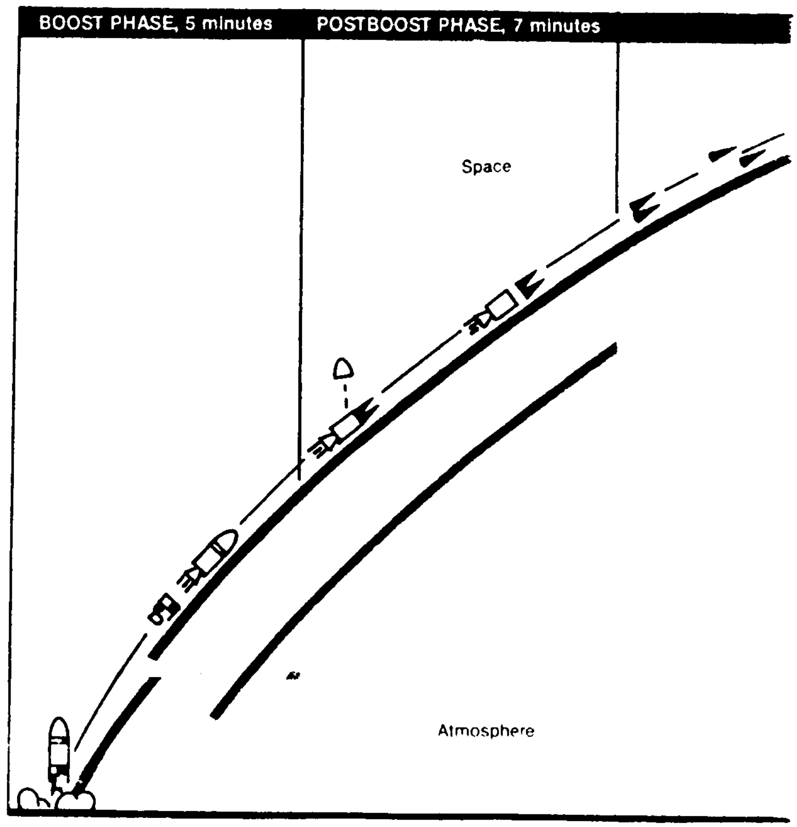
Because the Soviets guard information about new strategic weapons even more closely than the United States does, the early tests of military hardware may be the first significant pointer to the capabilities of an addition to the Soviet arsenal. For the development of nuclear missiles, two types of tests are crucial. The missile's rocket booster, which delivers warheads, is launched with a variety of instruments that relay information continuously from key subsystems via radio telemetry. The nuclear warheads themselves are tested separately in underground detonations.

The United States monitors Soviet missile flights with a complex network of satellites, listening posts, and other intelligence stations. The Soviet tests fall into several categories. Developmental tests of new missiles take place 25 to 50 times each year. The SS-X-24 ICBM and the SS-N-X-23 submarine-launched ballistic missile (SLBM) are believed to be undergoing such tests now. These tests are more relevant to verification than the 25 to 75 reliability tests carried out annually by the Soviets, in which older missiles are fired from their silos. Much less telemetry data is generally transmitted during reliability tests.

Missile tests also include launches of so-called theater systems, with ranges of less than 5500 kilometers. No arms control agreements cover these missiles, which include the U.S. Pershing II and ground-launched cruise missiles and the Soviet SS-4 and SS-20 intermediate-range missiles.

U.S. verification monitoring generally focuses on two Soviet sites where new ICBMs are launched. Liquid-fueled ICBMs, like the SS-17, SS-18, and SS-19, are launched at Tyuratam, near the

MISSILE TRAJECTORY: TYURATAM TO KAMCHATKA



Launch: Tyuratam Cosmodrome, Kazakh, USSR

BOOST PHASE

Infrared sensors on satellites indicate that a missile has been launched and reveal how long each stage of the missile burns. Other satellites and ground-based stations intercept telemetry from missile components like the guidance system. During the launch, over-the-horizon radars track the missile by bouncing signals off the ionosphere and into the launch area. Other radars follow the trajectory when the missile climbs high enough for its image not to be blocked by the curvature of the earth.

POSTBOOST PHASE

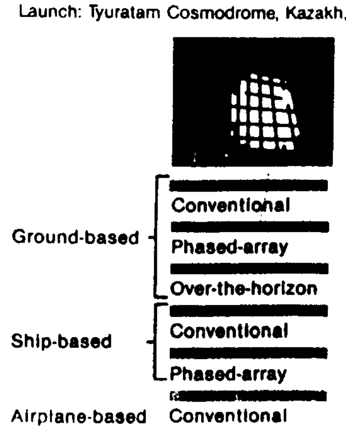
Radars trained on the missile determine the number of reentry vehicles and the velocity and trajectory of each. Satellite- and ground-based intercept stations continue to gather the barrage of telemetry. During postboost, important data is transmitted from the multiple independently retargetable vehicle bus, which is maneuvering to release the warheads.

MID-COURSE PHASE

Phased-array and conventional radars continue to track the velocities and trajectories of the warheads. The warheads are seldom equipped with instruments, so there is often no telemetry to be intercepted during this stage.

REENTRY

Radars on land and on ships follow the reentry vehicles as long as possible before impact. Infrared and optical telescopes on airplanes record the descent; the infrared spectra emitted by the glowing nose cones tell scientists what the cones were made of.



RADAR

U.S. radar capabilities for monitoring Soviet test missiles launched from Tyuratam include conventional radars at Diyarbakir, Turkey, and a phased-array radar on Shemya Island, near Alaska. A phased-array radar is part of the complement of electronic surveillance systems on the *Observation Island*, a signal-intercepting ship that monitors the mid-course and reentry of missiles. Less is known about the over-the-horizon radars operated by the United States for monitoring missile launches. One such system may be in Cyprus.

Aral Sea in southwestern Asia. Solid-fueled rockets, like the SS-X-24 and SS-25, are launched at Plesetsk, about 300 kilometers southeast of the White Sea, in the northernmost region of the eastern Soviet Union. Flights from both sites can be directed toward either the Kamchatka Peninsula or the northern Pacific Ocean [see map, pp. 44–45].

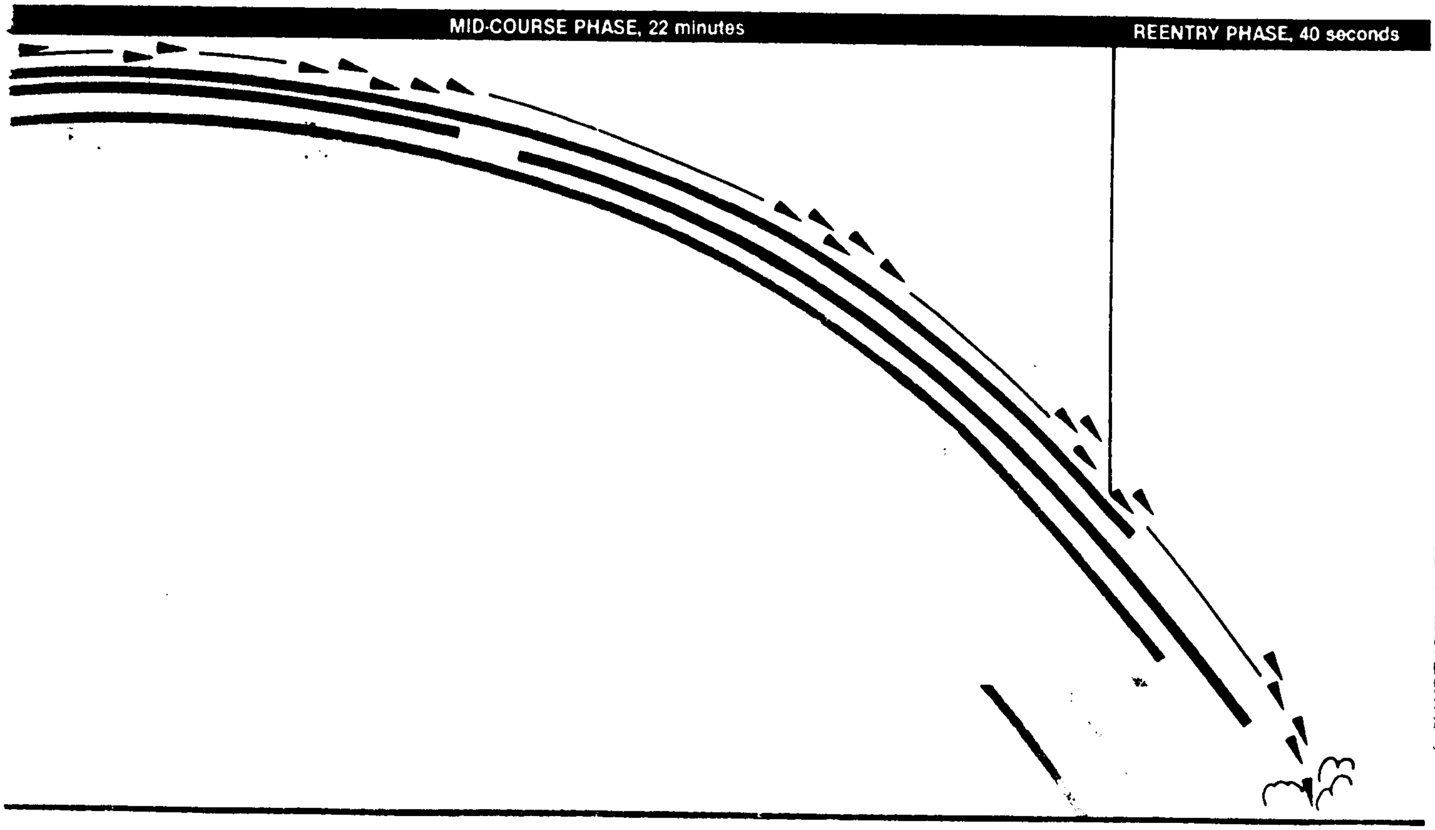
All of the developmental tests, and all but perhaps one or two of the reliability tests, are directed toward the peninsula, according to Matthew Bunn, a research fellow at the Massachusetts Institute of Technology's Center for International Studies. Under the SALT II agreement, the Soviets need not notify the United States before starting such tests.

The SALT II treaty requires the superpowers to notify one another "well in advance" before launching a test missile that will travel beyond national borders or before launching more than one missile. This provision is intended to prevent such tests from being interpreted as first strikes at the other side. The only advantage to the Soviets of launching a test toward the northern Pacific is the opportunity to test a missile over its full flight range.

Even without the advance notice, the United States is usually tipped off by several signs shortly before a missile test, Bunn noted. A sudden increase in communications from the launching and impact areas, coupled with a flurry of activity at the sites, as observed by photoreconnaissance satellites, is generally all the indication that is needed.

Once the Soviet missile is launched, U.S. intelligence resources, like signal-intercept stations, are trained on the site in a well-rehearsed sequence designed to capture as much of the telemetry as possible. The ideal for the United States, Bunn explained, would be to collect as much information as it gathers during one of its own missile tests.

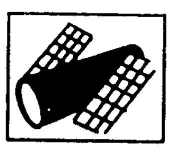
The volume of information transmitted from missile to ground during test flights—by both the United States and the Soviet Union—is prodigious. The Trident, one of the U.S. submarine-



TELEMETRY INTERCEPTION

Only space-based antennas can intercept telemetry from launch to impact. The United States has the Rhyolite, Argus, and Magnum satellites for this purpose in geosynchronous orbits, as well as a variety of intercept satellites in lower orbits. The *Observation Island* and specially modified RC-135 aircraft also have systems for intercepting any telemetry that may be emitted during the later stages of the flight. Ground stations in Turkey and China intercept telemetry transmitted during the boost and postboost stages.

Ground-based
Ship-based
Airplane-based
Satellite-based



OPTICAL SENSORS

The U.S. Defense Support Program satellites are equipped with infrared sensors for detecting the launch of missiles. During reentry, infrared sensors on RC-135 airplanes record the spectra emitted by the glowing nose cones, and telescopic movie cameras record the descent.

Airplane-based
Satellite-based

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launched ballistic missiles, was tested with a sophisticated pulse-code-modulated telemetry system of 192 channels. Each channel was sampled 400 times a second, for a total data rate of 614 400 bits per second.

The channels relay information from rocket subsystems, like the MIRV (multiple independently targetable reentry vehicle) bus, which holds the mock warheads until they are released as the rocket ascends after the boost phase. Data from the gyroscopes and accelerometers is also telemetered, as are the rates of flow in the fuel lines. In addition, there may be hundreds of sensors for measuring temperature, strain, and vibration throughout the missile. The data from many of these sensors may be multiplexed together and transmitted over a single channel.

Although much of this information is useful intelligence, only a fraction is needed to verify compliance with arms control treaties. Nor have the treaties addressed the accuracy of missiles, which can be estimated by comparing the information from the gyroscopes, which reveals the missile's own bearings, with highly accurate position readings made with radars on the ground. (Computations of accuracy made in this fashion are not dependent on factors that can be easily tampered with, as is the case in using photoreconnaissance satellites; Soviet soldiers at one time routinely raced to the scene of missile impacts on the Kamchatka Peninsula, to fill in the craters and dig phony ones elsewhere before U.S. photoreconnaissance satellites orbited overhead.)

Two missile characteristics covered by the SALT II treaty are the number of warheads on the MIRV bus (limited to 10 for ICBMs and 14 for submarine-launched missiles) and the throw weight—the combined weight of the warheads, the warhead decoys, and the mechanisms that aim and release them. There are several restrictions on the throw weight. Many of these prohibit reductions in the weight of the warheads, because the lighter the warheads are, the more that can be added to the missile.

Monitoring the number of warheads carried by the MIRV bus can be done with a good radar track of the missile during its postboost phase, when it is coasting through space in a parabolic trajectory. During this stage the missile orients itself with a characteristic pattern, once for each warhead or decoy that it releases. These movements, as well as any objects that may be released, are easily discernible with advanced radars, even from thousands of kilometers away. If the telemetry data from the missile's MIRV bus is available, it provides more detailed information on the sequence of movements, which can be complex.

However, during some tests missiles release nothing, although they maneuver as though they were releasing a warhead or a decoy. This may be behind the disagreement between the U.S. Central Intelligence Agency and the Defense Department concerning the number of warheads carried by the SS-18. Although the missile has so far carried no more than 10 warheads, it is said to have 14 positions in which warheads can be placed, and on some flights it has maneuvered as though it were releasing more than 10 warheads. Extra positions are not unusual in missile designs: the U.S. MX missile has 11 mechanical positions for warheads, although it was designed to carry only 10 warheads.

Determining the throw weight is a more difficult challenge, because information from several sources must usually be combined. One way of determining the throw weight is to compute it from the thrust and acceleration, using simple Newtonian physics. The thrust may be determined from telemetry readings of fuel flows and other engine data, while acceleration is obtained with either radars or telemetry readings.

The only intelligence resources that can pick up telemetry during the first few seconds of a missile launching are signal-intercept satellites, as the rocket has not yet climbed above the horizon of ground- or airplane-based intercept stations. The United States operates a variety of satellites to detect telemetry early on.

In geosynchronous orbit are at least four Rhyolite satellites, built by the TRW Corp. for the National Reconnaissance Office (NRO). (The existence of the NRO has not been confirmed by the U.S. government, but the organization is said to be administered jointly by the CIA and the Department of Defense for the purpose of launching and operating spy satellites.) Two Rhyolites—one operational and one spare—reportedly monitor the Tyuratam launching site, and another pair monitor the base at Plesetsk. The satellites were launched in 1970, 1973, 1977, and 1978, according to Desmond Ball, director of the Strategic and Defense Studies Center at the Australian National University in Canberra. The existence of the satellites became known to the public in 1977 as a result of the arrest and conviction on espionage charges of Christopher Boyce, a TRW employee, and his cohort, Andrew Daulton Lee. The two sold extensive technical information about the satellites to agents from the Soviet Embassy in Mexico.

To monitor weak telemetry signals of only 10 watts or so from geosynchronous orbits 22 300 miles high the satellites use enormous parabolic antennas more than 20 meters in diameter. After the Rhyolite satellites were compromised by Boyce and Lee, the U.S. changed the code name to Aquacade, although the purpose of this change is unclear.

How useful the Rhyolites currently are to the United States is, of course, a well-kept secret. The receiving and control station for the surveillance satellites, located at Pine Gap, an Australian military compound, is reportedly expanding rapidly. Ball of the Australian National University told *Spectrum*: "Every time I talk to people out there, they say they're keeping one step ahead of the Soviets."

At least two geosynchronous satellites, successors to the Rhyolites, have been launched in recent years, Ball added. The Argus (the first two letters stand for *A*dvanced *R*hyolite, according to Ball) was launched in 1975, and the Magnum was carried aloft by the space shuttle Discovery in January 1985.

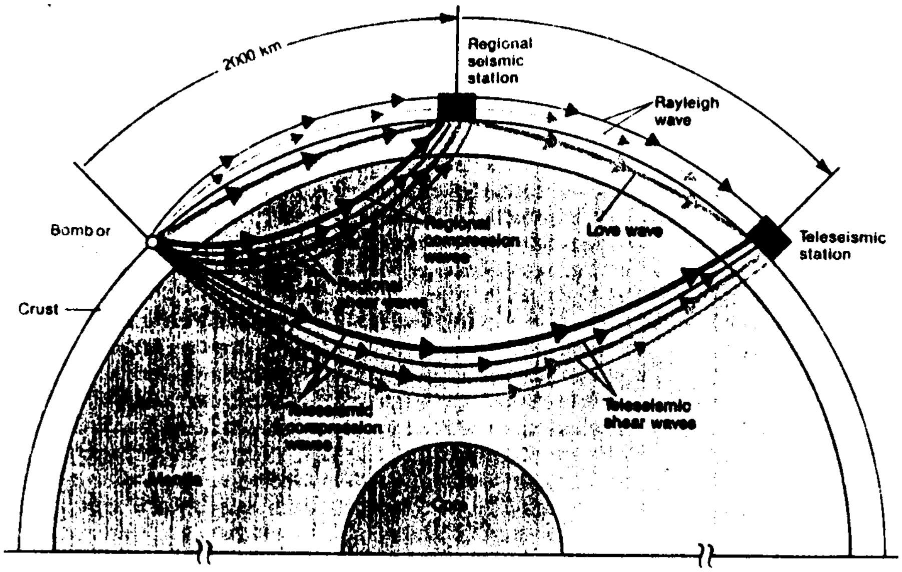
Apparently the CIA, through the National Reconnaissance Office, does not have a monoply on intercepting telemetry in space. The National Security Agency, the Defense Department's signal-intelligence arm, operates the Chalet series of geosynchronous satellites, Ball said. Telemetry-intercept capabilities started with the second satellite in the series, which was launched in 1978.

Sensitive though the geosynchronous satellites are, they can be foiled by extremely low-power signals, so the United States operates a number of satellites in lower orbits. They have better reception, but they may be in an obstructed position when a Soviet missile launching takes place. Little is known about the lower-orbit satellites other than that some apparently serve both military and intelligence functions, like photoreconnaissance, military communications, and signals intelligence.

One of these satellites, the KH-11, used primarily for photoreconnaissance of Soviet weapons stockpiles from an elliptical orbit 240 kilometers at its lowest point, can also intercept signals, according to some reports. Two other satellites, in highly elliptical polar orbits identical to those used by Satellite Data Systems, have never been identified publicly and are probably intelligence satellites, according to aerospace experts. Since these satellites spend 11 hours above the Northern Hemisphere during each orbit, they would be useful for a variety of signal-intelligence chores, including intercepting telemetry data.

U.S. satellites and other airborne platforms intercept telemetry immediately after a Soviet missile launching, but once the missile is well into the boost phase, ground-based intercept stations begin picking up the signals. Ground-based stations can use much bigger antennas and more elaborate receivers than would be practical for orbiters. For Soviet launches from Tyuratam, for example, U.S. stations in Diyarbakir, Turkey, begin receiving telemetry data when the missile is about 400 km high, according to the July 27, 1979, issue of *Science* magazine.

Two intercept stations in China, at Korla and Qitai in the Tien Shan Mountains, 1100 km southeast of the Soviet border, also monitor the Tyuratam flights, according to Ball. The stations, designed and built by the CIA, are operated by the Chinese under an agreement negotiated in 1980 by Zbigniew Brzezinski, then U.S. national security advisor.



[2] Earthquakes and underground nuclear tests can be differentiated by the relative magnitude of the different types of seismic waves they emit. Earthquakes produce a relatively large proportion of Rayleigh and Love waves that travel just below the earth's surface. Underground explosions primarily emit compression waves, one of the two main types of "body" waves that travel through the earth's crust and mantle to regional and teleseismic stations on the earth's surface.

The stations receive telemetry signals from test missiles before the stations in Turkey do. The United States and the Chinese share the data gathered by the stations.

Missile flights from the Plesetsk range to the north are monitored from Norway. Various accounts have listed six, seven, or eight signal-intelligence stations in Norway, although it is unclear whether all are useful for receiving telemetry from tests at Plesetsk. The stations are operated and staffed by the Norwegian government, but the United States has access through the CIA to all of the data they collect. The CIA helps operate the stations.

When the revolution in Iran led to the loss of U.S. intelligence bases there in 1979, U.S. congressional hearings were held to determine whether other resources would be adequate for verifying Soviet compliance with the SALT II treaty, which was being negotiated at that time. The question was urgent because the U.S. stations in Iran, which included a radar site and two signal-intelligence posts, were said to be the best the United States had for monitoring tests at Tyuratam. The stations could reportedly intercept telemetry signals from Soviet missiles at an altitude of only 100 km.

The loss of the U.S. intelligence bases in Iran, the compromise of the Rhyolite and Argus satellites, and the normalization of relations with China culminated in the late 1970s in major shifts in U.S. intelligence. The intercept posts near Korla and Qitai in China were built as replacements for the lost stations in Iran, according to Ball. In the interim, the United States sought to fly specially modified signal-intercepting aircraft above Turkey and Pakistan during Soviet tests at Tyuratam, possibly in return for generous trade concessions.

The losses of telemetry monitors in Iran prompted the National Reconnaissance Office to direct the National Security Agency to include telemetry interception on the Chalet satellites, according to Ball. The Chalets were originally intended strictly for communications intelligence.

One of the most significant developments of the late 1970s was the heavy encryption of missile telemetry data by the Soviet Union, starting with test flights of the SS-18 in the summer of 1978. Some authorities have speculated that the impetus came from the espionage convictions of Lee and Boyce in the summer and fall of 1977, which ended any reason for the Soviets to appear to be unaware of monitoring by the Rhyolites. Other experts, however, discount the timing as coincidence, since the Soviets had known for years about U.S. efforts to intercept their missile telemetry.

The SALT II treaty permits both sides to encrypt telemetry. But it also specifies that "neither party shall engage in deliberate denial of telemetric information, such as through the use of telemetry encryption, whenever such denial impedes verification of compliance with the provisions of the treaty."

Many U.S. government officials and other experts believe that the Soviets' encryption of telemetry is extensive enough to violate the treaty. Admiral Stansfield Turner, who was director of the CIA from 1977 to 1981, said: "If they are [encrypting] close to 100 percent, then we cannot verify SALT II adequately." One former Defense Department official told *Spectrum* that on flight tests of new Soviet missiles, like the SS-25, as much as 95 percent of the telemetry is sometimes encrypted, although with older missiles it is much less.

However, some experts see U.S. accusations of several specific SALT II violations as proof that verification capabilities have not been completely eroded by encryption. A long-standing U.S. charge is that the single warhead on the SS-25 is less than 50 percent of the throw weight of the missile, thus violating the treaty.

"If we can monitor that, then we're getting enough telemetry," asserted Ralph Earle Jr., who was chief negotiator for the SALT II talks and director of the Arms Control and Disarmament Agency from 1980 to 1981.

"It's the kind of issue that provides endless sources for dispute, because of the behavior of the Soviets and the attitude of die-hard U.S. arms control critics," observed Michael Krepon, a senior associate at the Carnegie Endowment for International Peace in Washington, D.C. "The combination is absolutely brutal."

Even if telemetry is heavily encrypted, it is not useless to U.S. scientists. By measuring the Doppler shift of the frequency of the received signal, an excellent estimation of the velocity and acceleration of the moving craft can be computed. In fact, indirect measurements like these, known as telemetry externals, are becoming the sole data the United States has to work with, according to one ex-Government source familiar with interception techniques.

Encryption is not the only means of keeping telemetry data secret. Another method uses very low-power, highly directional beams to telemeter the data back to the control center. There is a limit to this technique, however, because tumbling of a missile or other disorientation would break the tracking station's contact with it for the highly directional telemetry, and it is unlikely that communications could be reestablished.

Missile scientists may choose not to transmit any telemetry, but to store all data collected by the missile's instruments in a "black box," which is ejected from the missile shortly before impact. A radio beacon in the box helps technicians subsequently track it down. This approach is somewhat risky because a mishap during the flight could mean the loss of all the data, defeating the purpose of the entire flight test. Nonetheless, the United States used this technique to collect data from the warheads of the Minuteman II missile. (This was not a violation of the SALT II treaty because the data from the warheads is not required for monitoring compliance with the treaty.)

Another drawback to this method is the slim probability that the black box carrying the missile data will be recovered by the other side. This chance may seem remote, but the United States in fact operated the Operation Sand Dollar program in the 1960s to recover Soviet test warheads from the floor of the northern Pacific.

U.S. claims new missile violates treaty

Not only the weight of the SS-25 warhead is suspected of violating SALT II; the United States also believes that the missile itself is a transgression. The treaty permitted the Soviet Union and the United States one new ICBM each when it was signed on June 18, 1979. The United States announced that the MX missile would be its new missile, and the Soviets designated the SS-X-24 as theirs.

In February 1983 the Soviets tested what appeared to be an entirely new missile. Designated the SS-25 by the United States, it has a range of 10 500 kilometers, according to the U.S. Defense Department. The missile carries a single warhead, although U.S. intelligence agencies believe the missile will be modified to carry three independently targetable warheads.

The Soviet Union countered the U.S. accusation with one of its own, claiming that the proposed U.S. Midgetman missile violates the treaty. The Midgetman originated three years ago as a small (less than 30 000-pound) single-warhead ICBM to be launched from a mobile platform. Martin Marietta Aerospace and the Boeing Co. are both working on designs for the missile for the U.S. Air Force, but no prototypes have been built.

The SALT II treaty defines a "new" missile as one that has a different number of stages than other ICBMs in the fleet or one that has a length, largest diameter, or launching or throw weight that differs from that of the others by more than 5 percent. The Soviets maintain that the SS-25 is a slightly modified version of their SS-13, a single-warhead ICBM first flight-tested in 1965. The United States contends that the missile is not similar enough to the older missile to be permitted under the treaty.

The SS-13 was the Soviet Union's first solid-fueled missile. It was flight-tested more than 15 years ago, when U.S. verification capabilities were considerably less advanced. Until recently knowledge of the details of the older missile was less extensive than for newer missiles like the SS-25. However, since the summer of 1984 the Soviets have launched several SS-13s, giving the United States another look at the missile.

According to one U.S. government official, the United States and the Soviet Union agree on the characteristics of the SS-25 but disagree on the throw weight of the SS-13. The dispute centers on the device that targets the warheads of the missiles, which is on the last stage of the SS-13. The targeting device of the SS-25, on the other hand, is on the missile's postboost vehicle. The Soviets contend that the device, as well as the decoy warheads of the SS-13, should be counted as part of that missile's throw weight. If the throw weight of the SS-13 is computed in this way, and the weight of the sensors and instruments of the SS-25 is not included with that missile's throw weight, the SS-25 cannot be considered a violation of SALT II, the Soviets maintain.

"It's a complicated argument, but the bottom line is that the SS-25 is not a blatant violation," said MIT's Bunn. "It's something that reasonable people could disagree about."

"It's more like a blatant bending of the rules," said Krepon at the Carnegie Endowment for International Peace. Nonetheless, the Reagan administration insists that the missile is a violation of the treaty.

Radars fill in the gaps

Complementing telemetry data is the information provided by a network of radar stations stretching from Diyarbakir, Turkey, to Shemya Island off Alaska. Radars are trained on missiles through most of their flights to determine velocity, trajectory, and the number of warheads released.

The kingpin of the U.S. intelligence radar network is the gargantuan Cobra Dane system on Shemya Island. Built by the Raytheon Corp. of Wayland, Mass., and completed in 1976, Cobra Dane is a phased-array radar, a system with a surface covered with thousands of microwave antennas. Phased-array radars steer their beam from side to side by introducing delays into the transmitting signals fed to the antennas.

The chief advantage of phased-array radars over conventional systems is that they can track hundreds of objects simultaneously. Their electronically steered beam can be shifted from target to target in microseconds. Conventional radars, on the other hand, are limited by the time it takes to physically move the entire antenna to redirect the beam. Phased-array radars are particularly suited for missile tracking, because during a missile's reentry phase, the descent of several warheads, the warhead bus, the last rocket stage, and perhaps dozens of fragments must be traced.

Cobra Dane's 29-meter surface diameter contains 34 768 antenna elements, 15 360 of which transmit radar pulses (the others are receive-only antennas). The antennas are powered by 96 traveling-wave tube amplifiers that together produce over 15 megawatts. The radar could spot a metallic sphere 7 centimeters in diameter from 1800 kilometers away.

Impressive though the capabilities of Cobra Dane are, its fixed location on the eastern edge of the Bering Sea leaves something to be desired. Long portions of the trajectories of missiles launched from Tyuratam toward Kamchatka are blocked from its field of coverage by the curvature of the earth. The radar begins tracking missiles about 3700 km away, when they are at least 650 km high and well into the mid-course stage. It can track the reentry over Kamchatka down to an altitude of about 160 km. For tests that splash down into the northern Pacific, it can follow reentry vehicles down to perhaps 25 or 50 km, depending on where the missiles land.

To extend the coverage provided by phased-array radars, the Air Force commissioned the Raytheon Co. to build a second system in 1979, on a 173-meter-long former merchant ship once used to launch ballistic missiles. The radar, known as Cobra Judy, is the hub of an extensive complement of electronic intelligence equipment. In all, 900 tons of ballast had to be removed from the Navy ship, the *Observation Island*, to make room for 750 tons of electronic equipment.

Cobra Judy is conceptually identical to Cobra Dane; the primary difference between the two is that the ship-based radar is only 11 meters high. Cobra Judy's 7-meter-diameter radiating surface [see Fig. 1] has 12 288 antenna elements, all of which can transmit as well as receive. The ship-based radar, when maneuvered close to the Kamchatka Peninsula, gives several hundred miles more coverage than Cobra Dane.

But even Cobra Judy cannot cover the early stages of flight tests, such as the boost and postboost. Two of the lost radars in Iran were believed to be useful for this purpose.

Speculation has continued for years over the extent of the U.S. use of over-the-horizon radars to peer deep within Soviet borders to record the initial launching of test missiles. Over-the-horizon radars differ from conventional and phased-array radars in that they overcome the range limitations posed by the curvature of the earth; they use the ionosphere to reflect signals to and from a target, just as high-frequency radios do. To "see" over the horizon by using the ionosphere as a giant mirror, over-the-horizon radars use frequencies between 5 and 30 megahertz. Cobra Dane and Cobra Judy, on the other hand, use frequencies higher than 1 gigahertz, which penetrate the ionosphere.

The existence of an over-the-horizon radar on a British military base in Cyprus has been reported but never confirmed publicly. The General Electric Co.'s Heavy Military Equipment Division in Syracuse, N.Y., and Raytheon's Data Acquisition Systems group in Wayland, Mass., are the leading U.S. suppliers of over-the-horizon radar gear.

The next generation of radars for monitoring missile tests will be inverse synthetic-aperture radars that not only determine the velocity, position, and size of airborne and orbiting objects, but provide a detailed image of them as well. Furthermore these radars will be able to provide images of missiles and warheads through rain, fog, dense cloud cover, and at night. They will also be able to provide detailed images of satellites in low-earth orbit.

Inverse synthetic-aperture radars can create images because they separately resolve the ranges and Doppler shifts of individual points on a spinning target. In effect, the radars use the motion of the target to simulate a very large antenna for high resolution. Experimental inverse synthetic-aperture radars have been built by the Environmental Research Institute of Michigan in Ann Arbor and Lincoln Laboratories in Lexington, Mass.

Looking for the double flashes of blasts

Monitoring weapons tests for compliance with arms control treaties covers not only the flight tests of missiles but also the tests of warheads and bombs. Monitoring the test blasts of nuclear weapons usually entails verifying at least three key facts: that the test was not in the atmosphere, the ocean, or in space; that the bomb did not have a yield greater than 150 kilotons; and, if more than a single bomb was tested at once, that the total yield of the bombs was not greater than 1500 kilotons. The first stipulation dates back to the Limited Test Ban Treaty of 1963, the second to the Threshold Test Ban Treaty of 1974, and the third to the Peaceful Nuclear Explosions Treaty of 1976.

Satellites that can detect atmospheric nuclear blasts anywhere are regarded as the one clear example of a technological catalyst that led directly to an arms control treaty. A confluence of two new developments—satellites and optical sensors—occurred in the late 1950s, precisely when the cold war between the United States and the Soviet Union had arms control negotiators on both sides eager to find a way to ease the fears and tensions that had developed.

The Vela series of satellites, built by TRW Inc. in Redondo Beach, Calif., made the Limited Test Ban Treaty possible. They were designed to detect nuclear bursts both in space and on the earth below. To detect blasts on the earth, the more difficult of the two requirements, the satellites had to distinguish the light flash produced by an atmospheric nuclear blast from other flashes, like lightning.

Atmospheric detonations of nuclear explosives produce two distinct flashes of about the same instantaneous brightness within 100 milliseconds of each other. This double flash is caused by the expansion of the spherical shock wave generated in the atmosphere by a nuclear blast. The first light peak occurs because the luminous shock wave is expanding faster than its surface is losing brightness. This situation eventually reverses, however, and the shock wave begins to dim. The shock wave is initially opaque to the light of the inner fireball, even though it is luminous. As it cools, it becomes more transparent to visible light, so light from the hot interior of the shock wave begins to escape. This causes the second flash.

The U.S. Vela satellites could recognize this double flash from their orbits more than 100 000 kilometers from earth—a third of the way to the moon. Twelve of the satellites were orbited in all, with the first two launched on Oct. 17, 1963—just one week after the Limited Test Ban Treaty went into effect. The last two were launched in 1970. The satellites had a projected lifetime of 18 months, but all functioned well beyond this design goal. Their most recent contribution was probably in 1979, when on Sept. 22 a Vela satellite recorded a characteristic double flash in the vicinity of Prince Edward Island, southeast of the southern tip of Africa.

Various theories at the time held that Israel or South Africa had tested a nuclear bomb. The United States dispatched aircraft to the area to collect air samples to be checked for radioactivity. No abnormal readings were discovered, although U.S. scientists said that the lack of radioactivity might be attributed to heavy rainfall in the area before they were able to sample the air. Or the air samples may have been collected in the wrong place—the Vela satellites were not capable of giving precise locations of suspected detonations.

The fact that the satellite that recorded the flash was more than 10 years old cast doubt on the finding. Also, U.S. scientists were puzzled by a mysterious time interval between the readings made by the two sensors on the satellite. Flashes on the earth's surface were recorded by the satellite's photometers at exactly the same instant. The lag between the two readings of the September 1979 event led some scientists to conclude that the source of light must have been very close to the photometers. One theory was that a meteor struck the satellite, chipping off a piece of the solar panel, which drifted in front of the two photometers in such a way as to reflect sunlight in a double flash. After an investigation, the official U.S. government position was that no nuclear explosion had taken place.

Jack Ruina, a member of the presidential panel that investigated the incident in 1979 and now an electrical engineering professor at MIT, said that the Vela satellites had detected every above-ground French and Chinese nuclear test that a satellite was in position to see. (France and China did not sign the 1963 treaty banning above-ground tests.) American University's Richelson added that there were 41 of these tests. In fact, the Defense Intelligence Agency and the Naval Research Laboratory reportedly continued to support the notion that an atmospheric detonation

Finding the key to the 'Puzzle Palace'

Admiral Chester Nimitz is said to have estimated the value of signal intelligence in the Pacific theater during World War II as equal to that of an additional fleet. Today, signal intelligence helps keep the peace in verifying compliance with arms control treaties.

Signal intelligence pervades U.S. verification efforts, from the monitoring of telemetry from a new Soviet strategic missile to the chance interception of a telephone call in which speakers discuss the specifics of an upcoming underground nuclear test detonation.

Although in some cases it falls within the purview of the Central Intelligence Agency, the Defense Intelligence Agency, and others, signal intelligence is primarily the domain of the 34-year-old National Security Agency. Although part of the U.S. Department of Defense, the NSA enjoys a high degree of independence from the parent organization—a recurring source of friction during the agency's brief history. In a promotional pamphlet, the NSA calls itself an "affiliate" of the Defense Department, adding that over 80 percent of its employees are civilians.

The NSA's tens of thousands of technicians, engineers, and scientists collect telecommunications through a worldwide network of intercept posts. Although nearly all types of communications—radio, telephone, and telex—from most of the countries in the world are targets, special efforts are focused on sensitive government traffic originating in Soviet bloc countries. A rare glimpse into the NSA's operations was provided during testimony in the trial of Ronald W. Pelton, a technician at the agency from 1965 to 1979, who was convicted in June of selling information about several secret NSA projects to Soviet agents in Vienna in 1980 and 1983. —G.Z.

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had occurred. After nearly seven years, however, the issue remains unresolved.

All of the Vela satellites are now nonfunctional, according to a former Defense Department official. Their role of scanning the earth's surface for atmospheric explosions has been picked up by the Defense Support Program (DSP) satellites, which perform a wide-ranging set of functions from early warning to nuclear blast detection. More than 10 of the satellites have been launched since the first ones were orbited in the late 1960s.

The DSP satellites are focused primarily on the Northern Hemisphere, the Defense Department source said. So an atmospheric test in the Southern Hemisphere, like the suspected incident near Prince Edward Island, would in all likelihood escape the notice of U.S. satellites today.

The lapse in coverage has apparently been extended by last January's tragic explosion of the space shuttle Challenger. The United States had planned to use the space shuttles to begin launching a new series of satellites next January. These satellites, known as the Navstar Global Positioning System, will be able to spot nuclear blasts anywhere on the globe when the complete series of 18 satellites is in orbit. Before the Challenger disaster, the United States hoped to have the system in place by the end of 1988. Now the program is on hold, along with all of the other projects scheduled to be launched on the shuttles.

The project is being sponsored by the Navy. The satellites, which will be in six circular orbits 26 600 km high, will also provide highly accurate position readings for military navigation. Eleven developmental Navstar satellites have been launched so far, the last four of which carried the integrated optical nuclear detection systems that will record atmospheric blasts and will be on all of the 18 operational satellites. The last of the developmental satellites was successfully launched last October from Vandenberg Air Force Base in California.

Starting with the tenth operational satellite launched, electromagnetic pulse sensors will also be included with the Navstar packages for monitoring detonations on the earth's surface. The pulse sensors are more precise than optical sensors for distinguishing nuclear blasts from other phenomena, particularly when cloud cover obscures the light flashes associated with such a blast. According to a source familiar with the design of the Global Positioning System, the detection capabilities of the satellites stretch far beyond what is required to monitor individual nuclear tests. In fact, the systems were designed for use in war, which means they can detect at least a hundred nuclear blasts a second, and instantly relay nuclear yield estimations and the precise location of each blast.

The satellites were designed to work in groups of four. All points on the earth will be visible at all times to four of the satellites, which will collaborate to provide precise positions. But with even three satellites, a good estimate of the position of a nuclear blast can be obtained, according to *Spectrum*'s source. For example, three satellites might indicate which wing of a Minuteman missile field was under attack.

Buried blasts yield higher frequencies

The last above-ground nuclear detonation was a test in 1980 carried out by China. But in the six years since that time, there have been dozens of underground tests by many nations, including the United States and the Soviet Union.

Monitoring underground detonations for compliance with the Threshold Test Ban is conceptually more straightforward than monitoring missile flights for compliance with the SALT II treaty. Although information is culled from several sources, like photoreconnaissance satellites and human intelligence, one method—seismic monitoring—is heavily relied on.

The United States uses a network of seismic sensor arrays operated by the Air Force Technical Applications Center to monitor for compliance with the Threshold Test Ban. There are Air Force arrays in Alaska, Australia, Spain, Turkey, and South Korea. In addition, there are three or four other arrays whose locations are classified at the request of their host countries.

The United States may soon have a new seismic station for listening to Soviet underground tests. According to the projected 1987 budget for the U.S. Department of Energy, in the fall of last year the United States and China began discussing a "cooperative effort" to build a regional seismic array in China. The main Soviet location for underground nuclear tests is near the town of Semipalatinsk, less than 500 kilometers from the Chinese border. If the joint U.S.-Chinese seismic array were installed as close as possible to Semipalatinsk, it would be near the U.S. telemetry-intercept stations at Korla and Qitai. Construction of the array could begin as soon as fiscal year 1987, according to the budget report.

The Chinese station is part of a U.S. effort to improve its seismic detection capabilities to the east of the Soviet Union. Other possibilities have also been explored, including the use of seismic sensors beneath the floor of the Pacific Ocean. In September 1982 the first of two Pacific experiments conducted by the Naval Ocean Research and Development Agency resulted in a partial success. Although the failure of drilling equipment and adverse weather prevented the group from inserting the main seismometer, an auxiliary unit designed and built at the Hawaii Institute of Geophysics was inserted into a hole 220 meters deep that was drilled in the seabed 5370 meters below the surface.

The seismometer was installed about 1500 kilometers due east of the Japanese island of Hokkaido. The auxiliary seismometer built by the Hawaii institute was a three-component station, able to sense seismic waves in three dimensions. The station, which collected data for 60 days, worked "spectacularly," according to J. Alan Ballard, who managed the program at the Naval Ocean Research and Development Agency.

The results achieved with the auxiliary undersea sensors were encouraging enough for the agency, with the help of scientists from the Scripps Institute of Oceanography in La Jolla, Calif., to undertake a second try with the 10-meter-long, 2000-pound main sensor. In February 1983 the sensor was successfully installed midway between Tahiti and the Tonga Trench in an area known to be highly seismic. The seismometer worked for only 40 hours with its recording devices on the ocean bottom before an electrical short shut the station down, but in that time it recorded an astonishing total of 64 earthquakes. The South Pacific site would not be very useful for monitoring Soviet test detonations, but it would provide data on French tests, which are carried out beneath the Mururoa Atoll. However, at present there are no plans to install a permanent station in the Pacific, according to Ballard.

To the west, the Soviet Union is well covered by at least two seismic arrays in Norway. Geologically, Norway is an ideal location for monitoring the Soviet Union, according to seismologists, because it is one of the few places where geological features like tectonic boundaries do not block seismic waves. "It's almost like being inside the Soviet Union, as far as geology is concerned," said Ralph Alewine, director of the geophysical sciences division of the U.S. Defense Advanced Research Projects Agency (Darpa).

The state of the art of U.S. seismological techniques is probably represented by the Norwegian Regional Seismic Array, also known as Noress. Built through a cooperative effort between the U.S. and Norwegian governments and opened in June 1985, Noress is a research array about 100 kilometers northeast of Oslo that was designed to determine the capabilities of seismic arrays for monitoring nuclear test explosions. It is not a part of the worldwide network operated by the U.S. Air Force for monitoring such tests, although the information it provides on Soviet tests is useful for this purpose.

The array differs from previous ones in several respects. For one thing, it is completely automatic and requires human attendance only for occasional maintenance. Data from each of the 25 sensors in the array's four concentric rings are sent via fiber-optic lines to a hub, where they are collected and retransmitted in a 32-kilobits-per-second stream to four receiving stations; a telephone link connects the hub with the Norwegian analysis center in Kjeller, while satellite links beam the information to U.S. sites in Virginia, California, and New Mexico.

The arrangement of the Noress sensors was painstakingly worked out to take advantage of geological features at the site. Researchers had a detailed knowledge of the geology of the area, based on years of Norwegian seismological research, and the array is one of the first to make use of negative correlation techniques. These enable researchers to let the background noise signals partly cancel one another by spacing the sensors to take advantage of the geological pattern intrinsic to the area.

Noress also represents a trend toward the use of smaller arrays to monitor higher-frequency seismic signals. Older arrays, sometimes called teleseismic arrays, were mammoth affairs that read signals with frequencies of 1 hertz or less. For example, the Large Aperture Seismic Array, built in 1964, occupied a significant portion of the eastern half of the state of Montana. In fact, Noress, which is about 3 kilometers in diameter, sits in the midst of an older teleseismic array called Norsar, much like the cup in a golf green. One of the sensors in the Noress array can detect signals with frequencies as high as 60 hertz, according to Darpa's Alewine.

Many seismologists believe that these high frequencies can propagate over huge distances via certain especially conductive geological paths. Noress uses one of these paths, in the western Soviet Union, to its advantage. Last July the array detected a Soviet test of a 0.25-kiloton nuclear bomb at Semipalatinsk, more than 4000 kilometers away. That explosion registered a magnitude of 3.5 on the Richter scale, and Noress can detect a 2.5-magnitude blast, Alewine said.

Glenn Zorpette

David Harris, a seismologist at Lawrence Livermore National Laboratory in Livermore, Calif., indicates the location of the Norwegian Regional Seismic Array, which is used to monitor Soviet underground tests of nuclear explosives.

Soviet moves surprise sovietologists

Despite these capabilities, seismological data on underground nuclear tests generally gives the United States nothing more than an estimation of the yield of a nuclear explosion. The reason is that the Soviets closely guard information concerning the seismology of nuclear explosions in their country. For example, although several Soviet journals cover geology, none publish papers on the seismology of Soviet nuclear testing—instead they describe U.S. tests. The U.S. tests are also routinely covered in the 10 or so U.S. geology journals.

The Soviets' secrecy in this regard sometimes takes on almost ludicrous proportions. As an experiment in international cooperation, the Geneva-based International Conference on Disarmament sponsored a program in which 40 countries exchanged data gathered by their seismometers on nuclear tests. The program ran from October 1984 to January 1985. During these three months the Soviets failed to report the seven tests conducted in their own country. The tests were picked up by virtually all of the other participating countries, including East Germany, Bulgaria, and Hungary.

Since U.S. seismologists lack precise information on the geology of the Soviet Union, they estimate the yields of nuclear detonations by using the geology of the United States as a model. Given the magnitude recorded by the seismometers, the yield is determined as though the test had been conducted in the United States, except the estimate is scaled with a bias factor to account for the differing geologies. In the absence of factual information, the accuracy of the bias factor is somewhat dubious.

This uncertainty is behind the disagreement between the CIA and the Defense Department over the method by which the yields of test explosions should be measured. The CIA uses a new bias factor that indicates lower yields.

The motivation for the CIA's decision in fact came largely from within the Defense Department, which has been reluctant to adopt the new figure. The CIA change was prompted by classified studies released by Darpa and the Air Force Technical Applications Center in October and November of last year.

The change was not the first time that the factor had been scaled down. The most recent revision was in 1977. An increase in the average magnitude of Soviet test explosions was reported after that change, and some U.S. government experts contended this was evidence that the Soviets had learned of the change and increased the magnitude of their tests accordingly.

Information accurate enough to leave no doubt about compliance with arms control agreements may require readings taken closer to the source, either with seismometers within the borders of the country performing the test, or with instruments at the very site of the detonation. The United States has proposed to the Soviet Union that both sides be permitted to monitor yields at the other's test site by using a technology known as Corrtex (for continuous reflectometry for radius versus time experiment). Variations of the technology have been used for about 25 years.

With Corrtex, a coaxial cable is inserted into a hole near the test bomb. Pulses are sent at regular intervals down the length of the cable to the bottom, where they reflect back to the top. When the bomb is detonated, the rate at which the cable is crushed by the expanding shock wave is measured by the change in the time it takes the pulses to reflect from the electrical short at the end of the cable. In this way, Corrtex gives a very precise measurement of the rate of expansion of the shock wave, which in turn gives an accurate indication of yield.

President Reagan invited Soviet leader Mikhail S. Gorbachev to send Soviet scientists to watch Corrtex in action in April at the site in Nevada where the United States conducts its underground tests of nuclear bombs. The Soviets, however, are interested in a moratorium on all underground testing (a comprehensive test ban). In fact, they began a unilateral moratorium last summer and have not tested a nuclear device of any kind since July 25, 1985. Under a comprehensive test ban treaty, instruments like Corrtex that measure yields are unnecessary, so it is perhaps not surprising that the Soviets did not respond to President Reagan's invitation.

The unilateral moratorium on underground testing has not been the only surprising Soviet move in recent months. Last May the Soviet Union agreed to allow nongovernment U.S. seismologists from the Natural Resource Defense Council in New York City to monitor Soviet underground tests from three seismic stations to be built by the U.S. scientists within the Soviet Union. In exchange, the Soviet Union would be allowed to send seismologists who work for the Soviet government to build and operate several monitoring stations within the United States, possibly in California.

Implementation of the proposal hinges on the approval of the U.S. government and the ability of the New York group to raise funds to build the seismic stations in the Soviet Union. The Natural Resource Defense Council, a not-for-profit organization of lawyers and scientists interested in arms control issues, sent a delegation to Moscow last spring to negotiate the agreement with the Soviet Union's Academy of Sciences.

Whether the seismic stations, if built, would contribute substantially to existing or future arms control treaties remains unclear. Nonetheless, the agreement was seen as significant by sovietologists because in the past the Soviets have often regarded all verification strategies that involve foreign scientists either on their soil or at the test site itself ("on-site" inspection) as excuses for espionage. Although the Soviets agreed in principle to on-site inspections in the Peaceful Nuclear Explosions treaty in 1976, a complex set of preconditions and stipulations virtually assured that no such inspections would ever take place.

Decoupled blasts: 'needles in a needle stack'?

Although the Reagan administration has decided not to negotiate a comprehensive test ban, such negotiations were a priority of the Carter administration in 1977–1980. The seismic requirements of verifying a comprehensive test ban, in which *any* detonation is a violation, no matter how small, are severe.

The first problem is distinguishing a nuclear test from some other source of seismicity, like an earthquake. For big seismic signals this is not difficult, because several features differentiate the two [see Fig. 2].

Seismic activity is characterized by a variety of types of waves. For distinguishing earthquakes from underground detonations, seismologists rely on two of these: compression, or "body," waves with frequencies of about 1 hertz, and surface waves with frequencies of about one cycle every 20 seconds. For earthquakes, the ratio of the magnitude of the compression wave to the magnitude of the surface wave is almost always much smaller than the same ratio for waves caused by an underground detonation. Moreover if seismologists can be sure that the origin of a seismic disturbance is more than 5 kilometers deep, the chances that it was caused by an underground detonation are almost nil, because of the impracticality of testing bombs at such depths.

However, the usefulness of these differentiations drops sharply for weak seismic signals, according to Thomas Bache, a senior scientist at Science Applications International Corp., a scientific consulting firm in San Diego, Calif. Also troublesome, Bache said, are the occasional earthquakes that exhibit many of the characteristics of underground explosions. This type of quake may be uncommon, but it is problematic nonetheless because there is always the possibility that it might be taken for a clandestine nuclear test. However, when events like these are detected, images from photoreconnaissance satellites of the area of the suspected test might be used in conjunction with the seismic data to establish whether a violation has occurred.

Contrary to what might be expected, the steady improvement of seismic sensor technology over the years has made the seismologist's job more difficult in many respects. As sensors have become more sensitive, the number of events the seismologist must consider has risen logarithmically. Distinguishing a nuclear test from a background of earthquakes is like trying to find the proverbial needle in a haystack. But separating a small, or perhaps intentionally muffled, nuclear test from routine chemical explosions used in mining, as seismologists are now trying to do, is a lot like "trying to find a needle in a needle stack," according to Bache. Large chemical explosions emit seismic signals that may be indistinguishable from those of small nuclear explosions.

Nonetheless some seismologists, such as Lynn Sykes of Columbia University and Jack F. Evernden of the U.S. Geological Survey, believe that very high-frequency seismic waves, of the type detected by Noress, can be used to separate nuclear detonations from other types of explosions. Such frequencies may also prove useful for detecting underground nuclear tests muffled by decoupling—insulating a bomb's blast from the surrounding earth by detonating it in a large underground cavity. With decoupling, most of the energy of the blast is dissipated within the cavity before the shock wave slams into its walls. Both the United States and the Soviet Union have carried out experimental decoupled detonations.

Even if U.S. seismologists can confidently detect decoupled underground explosions and differentiate them from chemical explosions, they may be overwhelmed by the sheer number of events they must interpret. The Soviet Union, for example, is the source of an estimated 10 percent of the world's seismicity. According to one source knowledgeable about Noress, the array detects seismic events with a magnitude of 2.5 or greater at a rate of more than 15 000 a year—an average of more than 40 a day. Many of these are large chemical explosions, or quarry blasts, in mines in Poland, Scandinavia, and the Soviet Union.

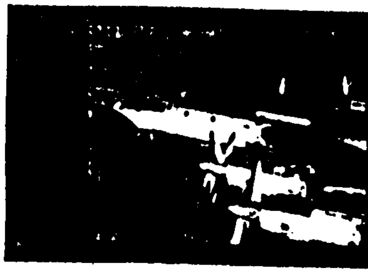
To help cut down on the number of events they must consider, scientists will soon be relying on powerful artificial-intelligence systems. Lawrence Livermore National Laboratory in Livermore, Calif., has already demonstrated a rule-based system. Two other developers, Science Applications International Corp. of San Diego, Calif., and Ensco Inc. of Springfield, Va., are competing for a sizeable Darpa contract for an artificial-intelligence system to be installed in the Noress array. Darpa hopes to have a prototype system on line within a year, according to John Orcutt, a geophysicist at the Scripps Institute of Oceanography.

The system will sift through thousands of seismic events recorded by the station's sensors and within seconds of a reading that appears to be a nuclear test, it will call attention to the suspicious signals so that a trained seismologist can take over. In hunting for nuclear tests, the computers will be programmed to recognize the differences between the seismic waves of explosions and those of earthquakes. But they will also have a knowledge base that may enable them to weed out the chemical explosions, for example. The program will know where chemical explosions frequently occur—say, in Finland—as well as where past nuclear tests have been carried out. The knowledge will be constantly updated; if an earthquake is recorded with an origin at a previously unknown seismic epicenter, this location will be stored for future reference.

The Air Force's Technical Applications Center (Aftac) has launched an independent artificial-intelligence program for monitoring its networks, according to Orcutt. The companies involved with the project are Teknowledge Inc. in Palo Alto, Calif., and Ensco Inc. Few details of this program have been released. One source told *Spectrum*, however, that it will eventually tie in all of the various worldwide Aftac networks, which are monitored at Patrick Air Force Base in Florida. Besides seismic sensors, Aftac's monitoring resources include satellites like the DSP series for detecting atmospheric or space detonations and sea-bottom arrays of hydroacoustic sensors for detecting underwater tests. The idea, according to the source, is to automatically pool resources in an area as soon as one of the sensors detects an incident. For example, a double light flash detected by a satellite might lead to any one of several responses, like dispatching aircraft to check for unusual radiation levels. The Aftac system will suggest the best possible strategy in cases like this.

How capable are U.S. technologies for keeping the peace? Reassurance was offered by Noel Gayler, a former director of the National Security Agency and commander in chief of the Pacific Forces. He said: "I am confident that we can verify, by national technical means, any violation that could affect our position relative to the Soviet Union."

The extent of the U.S. monitoring capabilities bears out Gayler's confidence. The United States can rely on these capabilities to know whether the Soviet Union is complying with treaties that limit the effectiveness of strategic weapons. But if both sides do not share a genuine interest in limiting the capabilities of weapons the most advanced monitoring systems will do nothing more than serve military strategists by telling them what new weapons they must counter. ◆



THE SOVIET 'SPY GAPS'

Any lag there may be in the USSR's technical systems for monitoring is offset by Soviet access to U.S. military intelligence

Throughout the summer of 1985 an internal debate raged within the Reagan administration: Should the United States continue to adhere to the unratified SALT II treaty—an agreement that many people believe the Soviet Union has violated? At issue was the fate of two U.S. ballistic-missile submarines: a new Ohio-class vessel, the Alaska, capable of launching Trident missiles, and an older Poseidon-missile submarine, the USS Sam Rayburn.

The Alaska was about to be commissioned; continued adherence to SALT II required that the United States remove the Sam Rayburn from service. Moscow was aware of Western media reports that President Reagan had decided to continue to adhere to SALT II and had ordered the Sam Rayburn decommissioned. But the Soviet leaders still wondered what the United States would do.

Sometime during the many weeks required to dismantle the U.S. submarine, Kosmos 1699, a Soviet reconnaissance satellite orbiting 180 kilometers above the eastern seaboard of the United States, no doubt trained its cameras on the Charlestown Naval Yard in South Carolina and began photographing dockside activities. Its pictures would have shown the Sam Rayburn's 16 Poseidon missiles being unloaded and work under way to render its missile tubes inoperable. Those pictures, sent back to Moscow, would confirm that the United States was continuing to comply with SALT II.

Arms control verification has been a topic of national attention in the United States for well over two decades. Not surprisingly, the main concern has been the U.S. ability to monitor Soviet compliance. But there is another side to the coin: Soviet ability to monitor U.S. treaty compliance affects Soviet willingness to consider certain arms control provisions. Do the Soviets have blind spots in their monitoring capabilities? It is doubtful.

The Soviet Union, like the United States, depends heavily on its national technical means to monitor compliance with arms agreements. Soviet capabilities include satellites, surface ships, and submarines off U.S. shores, as well as monitoring stations on land. In contrast to the United States, however, the Soviet Union can also take advantage of the openness of U.S. society, through a vast array of human intelligence sources and methods, to monitor arms control compliance.

Soviet 'spy' satellites

The Soviets operate three types of "spy" satellite. Over the past 15 years the workhorse has been a third-generation film-imaging system with an average mission lifetime of 12 days. This brevity is dictated by the film capacity of the satellite and by Soviet needs for timely reconnaissance. The satellite's entire load of pictures must be returned to earth in a special reentry module for recovery and processing in the USSR.

When designated for area search missions, like looking for new ICBM fields or antiballistic missile sites, the Soviet satellites are boosted into an almost circular orbit of 415 by 350 km. Close-look missions, on the other hand, use significantly lower perigees, or orbital low points—about 175 km. Photoreconnaissance orbital inclinations with respect to the equator vary between 65 and 82 degrees, but all allow coverage of the entire United States. With an average 90-minute orbital period, the satellite makes several passes over U.S. territory each day. Controllers can adjust the orbit by firing on-board maneuvering rockets so that the perigee point can be moved over different targets or so the same target can be photographed on successive days under similar lighting conditions. About 20 of these third-generation photoreconnaissance satellites were launched in 1985, with nine flying area search missions.

Since 1980 the Soviets have also been using fourth-generation, film-return satellites, including Kosmos 1699. (The Soviets designate most of the satellites by the Kosmos name followed by a number based on launch order.) With mission lifetimes of about 50 days, these satellites provide timely imagery by intermittently ejecting film capsules for recovery in the USSR. They are used exclusively for close-look missions, flying orbits of 320 by 170 km with inclinations around 67 degrees. No fourth-generation photoreconnaissance satellite was launched in 1985.

Last year the Soviets conducted their third test of a fifth-generation reconnaissance satellite, which will become operational in the late 1980s. It will conduct video imaging missions and use digital transmission to send pictures to receiving stations in the USSR. The advantages of this system are obvious: picture taking is not limited by film capacity, imagery is more timely, and mission lifetime is extended considerably. Since video imaging has long been used by Soviet interplanetary spacecraft, the delay in applying this technology to photoreconnaissance may have been caused by the comparatively poor resolution

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Compared with U.S. publications, Soviet literature contains little useful intelligence information on military projects.

capabilities of Soviet imaging technology.

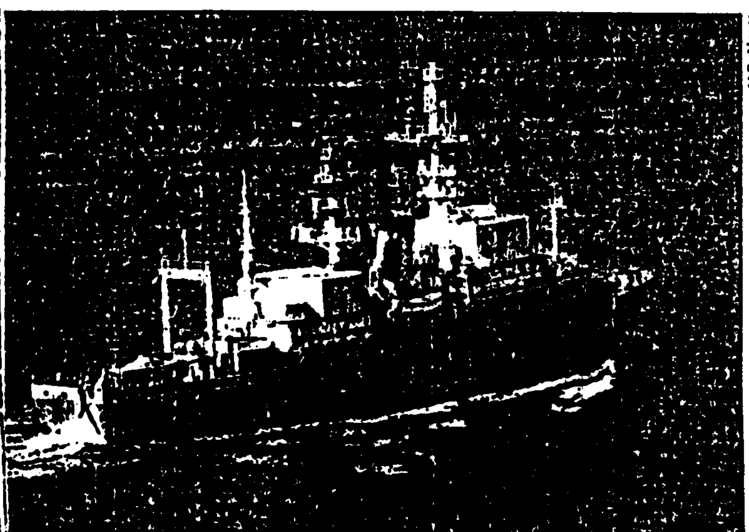
There is no public information on the resolution capabilities of Soviet reconnaissance satellites. But an article in the November 1985 issue of the Soviet military journal *Zarubezhnoye Voyennoye Obozreniye* (Foreign Military Review) reports that ground resolutions on the order of 1.0 to 2.0 meters are generally sufficient to detect and identify such strategic systems as ICBM launchers, aircraft, and major nuclear weapons components. The Soviet video imaging satellite is probably intended for this kind of general surveillance mission.

The same source reports that more detailed analyses—like those for monitoring the SALT II agreement—require resolutions around 0.3 meter. There is no reason to doubt that Soviet close-look film systems can provide such resolutions—a capability that the Soviets credited to the United States as early as 1970.

Soviet manned space stations—Salyut and the more recent Mir—also play a role in photographic and visual reconnaissance. Since 1977 the Salyut space stations have been manned an average of six months each year. Soviet space stations orbit at between 280 and 350 km, inclined about 51 degrees to the equator, and have orbital periods around 92 minutes. From 300 km, Soviet cosmonauts are able to conduct area search surveillance and, more important, they could test prototypes of new reconnaissance techniques and technologies, such as multispectral cameras, solid-state video imaging, and infrared systems.

There is a long history of visual reconnaissance of land and sea "targets" from Salyut space stations. The May 1984 issue of the Soviet Air Force journal *Aviatsiya i Kosmonavtika* (Aviation and Cosmonautics), for instance, describes how Salyut-7 crews used special color atlases to monitor ocean dynamics and correlate changes in ocean biological content. Monitoring these "biowakes" (plant and microorganism disturbances on the ocean surface) may be applicable to the detection and tracking of ballistic-missile submarines. While not necessary to monitor compliance with existing treaties, such capabilities would be useful under any future agreements that might limit strategic submarine operations.

The Soviets also operate a space-based radar ocean reconnaissance satellite (Rorsat) that, while not a true imaging system, uses active radar to detect and identify surface ships day or night, through cloud cover. The satellite orbits at about 400 km and its radar system has a resolution of about 40 meters. Besides tracking aircraft carriers, Soviet Rorsats may also be able to detect submarines carrying strategic ballistic missiles, when they are traveling on the surface. A more advanced version with finer resolutions, however, would be needed for detecting aircraft and land-based missiles.



U.S. Navy

The Soviet Primorye-class intelligence ship SSV-502 can collect various kinds of signal-intelligence information during strategic missile flights from the two U.S. missile ranges, on the Pacific and Atlantic coasts.

Keeping track of U.S. communications

The Soviets maintain two constellations of signal-intelligence satellites. The older is made up of six orbital planes spaced 60 degrees apart. In each plane, a single satellite orbits at about 650 km with an inclination of 83 degrees, completing one revolution in about 98 minutes. A newer constellation is being established at about 850 km with an inclination of 71 degrees. It is too early to tell what the final constellation configuration will be.

Some Soviet signal-intelligence satellites collect emission data from U.S. radar development programs. This is essential for verifying the 1972 Anti-Ballistic Missile Treaty, especially where air defense and antimissile technologies overlap. Other satellites collect telemetry transmissions during tests of weapons such as ballistic missiles, cruise missiles, and strategic bombers. The Soviet satellites also attempt to tap into U.S. political, military, and industrial communications networks in the hope of picking up useful information about U.S. military research and development.

Whereas the United States operates a host of land-based signal-intelligence stations in countries on Soviet borders, the USSR maintains a large sea-based system—over 70 intelligence collection ships and specially equipped trawlers and submarines. A sophisticated Primorye-class cruiser is frequently stationed near the U.S. Pacific test range station at Kwajelein Atoll. Displacing about 4000 tons and carrying a crew of 120, the ship is designed to intercept and analyze a wide range of telemetry, electronic emissions, and communications signals. It has a complete signal-intelligence analysis center with data links to other Soviet ships, aircraft, and satellites.

Because all firing tests of U.S. intercontinental ballistic missiles, antiballistic missiles, and submarine-launched ballistic missiles are conducted in either Atlantic or Pacific test ranges, the Soviets can acquire most information about them by deploying ship-based intelligence collectors. Indeed, Soviet intelligence ships often move into the test ranges, since the U.S. tests take place over international waters.

In one notable instance in 1982, *Aviation Week and Space Technology* reported, a Soviet Moma intelligence ship loitered within 500 feet of the U.S. ballistic-missile submarine Ohio as it was preparing to test-fire a Trident missile in the Atlantic test range. The launching had to be delayed until the Soviet ship was forced back—to a distance of just 6000 feet! Comparable U.S. land-based signal-intelligence facilities are many hundreds of kilometers—in some cases thousands—from Soviet test ranges.

Cuba undoubtedly serves as a signal-intelligence post for Soviet monitoring of Cape Canaveral, Fla., and other nearby test stations. The Cuban listening post intercepts transmissions from U.S. communications satellites in geosynchronous orbit, learning much about U.S. research and development programs by listening in on conversations between the many military, space, and industrial centers in the southern United States.

At Soviet diplomatic offices in the United States, a large network of posts specialize in collecting communications intelligence. The Soviet consulate in San Francisco, for example, which has an unobstructed view of one of the Pacific Telephone Co.'s main microwave towers, is equipped with an array of high-frequency and microwave antennas on its roof. By intercepting communications from Silicon Valley's defense industries and nearby military bases, the Soviets may acquire pieces of information on the intended guidance system design for the Midgetman missile or progress on command and control systems for the U.S. Strategic Defense Initiative.

The Soviet intelligence services also operate a constellation of 24 store-dump communications satellites that receive data from remote transmitters, which they store and retransmit on command. This technology might enable the Soviets to covertly place remote signal-intelligence collectors on U.S. territory near military bases, weapons development centers, and test ranges. These elec-

Inside Soviet Intelligence

Practically all Soviet monitoring systems used for arms control verification are controlled by the Ministry of Defense—more specifically, by the Main Intelligence Directorate (GRU) of the General Staff. The GRU is responsible for military intelligence collection and analysis, with most of its manpower distributed among operational forces in the field. It is estimated that over 5000 officers work at GRU Headquarters, located at Khodinka airfield in Moscow.

The GRU is divided into over a dozen geographic and functional directorates. Those directly involved in verification work include the Sixth Directorate, which controls military signal-intelligence operations; the Ninth Directorate, which collects and analyzes foreign military technologies; and the Space Intelligence Directorate. The latter reportedly manages the Soviet space intelligence program, including the research and development of new photoreconnaissance systems. The GRU is also very active in human intelligence collection; the Second Directorate is responsible for spying in the United States and Canada.

Better known in the West is the KGB, the Russian acronym for the State Committee on Security. The KGB, as the "sword and shield" of the Communist party, has responsibilities ranging from foreign intelligence and covert actions to internal security and suppression of domestic dissent. The KGB workforce is estimated to exceed a half million, controlled from KGB headquarters at Dzerzhinsky Square in Moscow. It too is divided into a number of geographic and functional directorates. KGB human intelligence contributions to Soviet verification efforts are made through the First Chief Directorate. This directorate is also responsible for KGB efforts to collect technical literature about Western defense, documentation, and equipment samples. The Eighth Chief Directorate collects signal intelligence for KGB analysis. —*S.M.M.*

tronic packages could collect many forms of signals and transmit them to the store-dump communications satellites for relay to the USSR.

Seismic monitoring lacks worldwide network

The Soviet Academy of Sciences operates a nationwide network of seismic monitoring stations that, among other tasks, attempts to detect and characterize U.S. nuclear weapons tests. There are reported to be about 200 stations in the network, almost all within the Soviet Union and Eastern Europe. A military intelligence collection section is most certainly located at each of the academy's main seismic monitoring facilities. A recent article in the Soviet military newspaper *Krasnaya Zvezda* (Red Star) claimed that the USSR operates 20 seismic stations dedicated to monitoring U.S. nuclear tests—analogous to the U.S. Air Force network that monitors Soviet tests. Whether the Soviet Defense Ministry's Main Intelligence Directorate (GRU) operates these stations independently is not apparent from the literature. Nevertheless, Soviet seismic monitoring does not have the advantage of a worldwide network, as the U.S. systems do.

The Soviet Union does, however, participate in many international geophysical research programs, including data exchanges with seismic stations around the globe. In this way the Soviets also gain access to many of the latest Western seismic monitoring technologies.

Open U.S. literature a boon to Soviets

The Soviet Union has one distinct advantage over the United States in verifying arms control agreements: significantly greater opportunities to employ human intelligence. While this most often evokes the image of spies, by and large the Soviets need not turn to cloak-and-dagger espionage. A ready source of information is open literature in the West, including journals like *Aviation Week and Space Technology* and *International Defense Review*. The Soviets might find this kind of information helpful in anticipating potential U.S. violations, so that they could concentrate their technical collection capabilities.

Similarly, reports by the U.S. executive branch, records of congressional hearings, and contractor studies are gobbled up by Soviet agents for clues to directions and trends in defense programs. During the late 1970s, for example, a number of visitors with "Eastern European" accents made stops at Air Force public information offices, where they picked up copies of a study on alternative MX missile basing modes. Soviet and East European "spectators" are present at most congressional hearings on defense.

Thus while the United States must wait for its national technical networks to detect Soviet weapons in advanced development or testing, the Soviets often learn of prospective U.S. weapons programs while they are still in the funding stage. For example, the Soviet decision to build the Krasnoyarsk early-warning radar—a violation of the ABM Treaty, in the U.S. view—was probably made in the late 1970s, and site work began soon after. Yet the radar was not detected by U.S. photoreconnaissance satellites until the summer of 1983. The United States was unable to raise the issue at the Standing Consultative Commission until after the Krasnoyarsk project was well into construction.

In contrast, the Soviets were aware of initial U.S. designs for the PAVE PAWS early-warning radar network to detect submarine-launched ballistic missiles—a design that the USSR contended was a violation of the ABM Treaty—years before construction began. Similarly, the Soviets have raised arms control compliance questions about the U.S. Strategic Defense Initiative program while it is only in the conceptual phase. A comparable Soviet effort would not become unambiguously apparent to the United States until it was well into testing, perhaps into development.

As former Soviet officer Viktor Suvorov describes in his book *Inside Soviet Military Intelligence*, Soviet agents also gain access to considerable information through contacts and operatives within the U.S. government and the extensive contractor community that supports the defense establishment. These sources are especially important to the Soviets to obtain information about so-called black programs—hidden U.S. defense projects—that might portend U.S. intentions to abrogate or violate arms control commitments.

It seems fair to conclude that Soviet technical collection capabilities for monitoring arms control compliance lag behind those of the United States. But this does not appear to have deterred the Soviets from entering into many arms control agreements with the United States over the past 25 years. Perhaps Soviet leaders have assessed their technical abilities as being adequate. Or perhaps they are not greatly concerned about the possibility of U.S. cheating. The openness of the U.S. government and society certainly acts to deter intentional U.S. arms treaty violations. Moreover, U.S. openness also reduces the need for Soviet technical collection by giving opportunities for human intelligence gathering. Such intelligence can be used to confirm indications from technical collection systems of many purported U.S. violations.

About the author

Stephen M. Meyer is an associate professor in the political science department at the Massachusetts Institute of Technology. He also directs the Soviet Security Studies Working Group at MIT's Center for International Studies. A consultant to the U.S. government, Meyer specializes in Soviet military affairs. Recent articles he has written include "Soviet Nuclear Operations," in *Managing Nuclear Operations* (Washington, D.C., Brookings Institution, 1986) and "Soviet Theatre Nuclear Forces," Adelphi Monograph, Winter 1983–84 (London, International Institute for Strategic Studies). ◆

Trying to overcome distrust with ingenuity in negotiations

Associated Press

U.S. negotiators, headed by Max M. Kampelman (left), face their Soviet counterparts, headed by Viktor P. Karpov (right), as strategic arms reduction talks resumed in Geneva on May 8.

Even under the best of circumstances—during the Peaceful Nuclear Explosions talks, for example, when both sides wanted a treaty and military stakes were low—arms talks can be tortuous. The problem is what drives the arms race in the first place: "They don't trust us, just as we don't trust them," said Warren Heckrotte, a physicist at Lawrence Livermore National Laboratory who was a technical advisor on nuclear test ban talks from 1961 through the late 1970s.

Heckrotte recalled how diplomats at the PNE talks in Geneva in 1974 hammered out a technique for monitoring yields of multiple blasts, which the Soviets used for engineering projects. The Soviets agreed that U.S. "designated personnel" (they disliked the term "inspector") could install sensors at the blast site, but insisted on examining each sensor to ensure that it could not gather additional intelligence. The United States insisted its personnel watch the examination to prevent the Soviets from tampering with the sensor. The Soviets, reluctant to reveal their inspection methods, proposed that the United States bring two identical sensors—one to be checked privately and the other with U.S. personnel watching; the United States could then use the latter sensor.

This was a significant concession, Heckrotte said, since the Soviets were essentially accepting the U.S. position. However, the United States refused the Soviet offer on the advice of specialists in Washington, who were concerned that the Soviets might be able to alter a sensor even with U.S. technicians looking over their shoulders.

The coin-flip solution

The Soviets "got mad as hell," said Heckrotte. "It looked like we might have blown the whole ballgame. But then we got ingenious."

The United States proposed that it bring two identical sets of sensing equipment, each with two recorders, to the test site in the USSR. The Soviets would choose one set to examine privately, while the United States would use the other to monitor the test. After the test, the flip of a coin would determine which of the test set's two recorders went to which country. If the United States tried to use illicit sensors, chances were 50-50 that the Soviets would find out.

After the U.S. presented this plan, Heckrotte recalled, "one of the Soviet technical people came up to me and said he understood it, but the people who make the decisions wouldn't. But about a month later they came back and said it's a deal."

Unfortunately, all this haggling has come to naught; the Soviets refused to implement the PNE verification procedures until the U.S. Senate ratified the treaty, which it has not done. —*J.H.*

said recently: "We should acquire for our own national security things that help our security best, and not the things that are igned simply to stay within the artificial limits of a flawed and ired treaty." Michael Krepon, a senior associate at the Carie Endowment for International Peace in Washington, D.C., ed Weinberger's position "technical unilateralism." Explained pon, "You do what you have to do regardless of what the other does."

he Administration has said that, if the Soviets make "radical" nges in their behavior, future agreements may be possible. But ne observers believe that the United States has in fact abanned arms control entirely in an effort to outrun the Soviets h a high-technology amalgam of offense and defense.

aid Warren Heckrotte, a physicist and arms control specialist at vrence Livermore National Laboratory: "On the one hand I ld see Reagan as being terribly skillful, holding things back et a good deal with the Soviets. But more and more I think he's really just not interested in a deal on any terms that would ke it possible with the Soviet Union."

ar Wars' and the ABM Treaty

Reagan's Strategic Defense Initiative—an effort to forge a ield" against Soviet intercontinental missiles—represents the st serious challenge to past and potential treaties. The program, netimes called Star Wars, repudiates the thinking behind the ti-Ballistic Missile Treaty, which sought to curb the prolifera- of offensive weapons by constraining defenses against them. Defense Department officials have urged that provisions of the ABM Treaty be "relaxed" to permit testing of SDI components. But if such tests proceed, the Soviets have warned, they will accelerate their own development of defensive systems; they will also quit the Strategic Arms Reduction Talks now under way in Geneva and build enough offensive missiles to pierce any U.S. shield.

The USSR has already accused the United States of violating the ABM Treaty with the detonation of an experimental X-ray laser at the Nevada Test Site last December.

The SDI may violate other treaties as well if it incorporates the X-ray laser or other so-called nuclear-pumped weapons now under consideration. To prove the viability of these weapons the United States may have to test them in the atmosphere or in space, violating the Limited Test Ban Treaty. (The United States maintains facilities on Johnston Island in the South Pacific that, according to the Defense Nuclear Agency, "would be a base of operations in the event the United States finds it necessary to resume nuclear testing in the now prohibited environments.") If the United States then decides to deploy the nuclear-pumped weapons in space it will also violate the Outer Space Treaty.

Ironically, U.S. officials have acknowledged that the Strategic Defense Initiative makes the United States more dependent than ever on arms control. James C. Fletcher, who headed the study that set forth the SDI two years ago, testified before Congress in 1984 that the "ultimate effectiveness" of the program would depend "on the extent to which the Soviet Union either agrees to mutual defense arrangements and offense limitations, or em-

I. Arms limitation treaties

Treaty and date signed	Parties	Significance	Major provisions	U.S. verification technologies	U.S. charges of noncompliance	Soviet responses to charges	Soviet charges of noncompliance	U.S. response to charges
Geneva Protocol June 17, 1925	119 countries, including U.S., USSR	First major multilateral treaty banning first use of weapons	Prohibits first use of poisonous gas or biological warfare	Only post facto means, including sampling, analysis of victims	USSR supplied toxic agents used in S.E. Asia and Afghanistan	Denial	U.S. used tear gas and chemical herbicides in Vietnam War	Nontoxic gases and chemical herbicides not banned
Outer-Space Treaty Jan. 27, 1967	87 countries, including U.S., USSR	Second treaty, after 1959 Antarctic Treaty, creating a nuclear-free zone	Bans nuclear arms and other weapons of mass destruction in space	Only indirect means, including ground-based telescopes and radar	None		None	
Nonproliferation Treaty July 1, 1968	116 countries, including U.S., USSR	Most extensive on-site inspection provisions of any existing treaty	Bans spread of nuclear weapons to nonnuclear states; prohibits development of nuclear weapons in nonnuclear states	On-site inspections (Int'l Atomic Energy Agency); TV cameras; tamper-proof seals	None		None	
Biological Weapons Convention April 10, 1972	90 countries, including U.S., USSR	First treaty banning production of weapons of mass destruction	Bans production and stockpiling of biological and toxin weapons	Only indirect means, including remote reconnaissance monitoring of production facilities	Same as for Geneva Protocol; also, USSR produced biological agents in Sverdlovsk	Denial	None	
Anti-Ballistic Missile (ABM) Treaty May 26, 1972 (product of first Strategic Arms Limitation Talks [SALT I])	U.S., USSR	First treaty constraining ABM technology; first recognition of "national technical means" of verification; prohibits interference with NTM verification; created bilateral commission to resolve disputes	Limits deployment of ABM interceptors to one site with 100 launchers; bans testing or deployment of other ABM systems; limits placement of large radar systems with ABM capability	Photoreconnaissance satellites (Big Bird, KH-11); ground- and space-based microwave sensors; other national technical means	Phased-array radar at Krasnoyarsk has ABM capability Soviet surface-to-air missiles being tested for ABM purposes	Radar is for tracking satellites, not missiles; will dismantle if U.S. dismantles stations at Thule, Greenland, and in UK SAMs are not ABM-capable	New U.S. radar stations at Thule, within UK, and elsewhere have ABM capability Testing of Strategic Defense Initiative components violates ABM treaty	Radars are for early warning, not ABM SDI is a research program and is thus permitted
SALT I: Interim Agreement on Offensive Arms May 26, 1972 (superseded by SALT II)	U.S., USSR	First treaty limiting strategic offensive weapons	Freeze on numbers of intercontinental and sea-launched ballistic missiles	Same as for ABM Treaty	ICBM silos not dismantled as required	Deployment of submarines delayed until silos destroyed	Shelters over Minuteman II and Titan II silos impeded verification	Shelters reduced or removed
SALT II June 18, 1979 (unratified by U.S., but both parties have pledged compliance; U.S. plans abrogation to counter alleged Soviet violations) Sources: see p. 75	U.S., USSR	First treaty to significantly limit offensive strategic weaponry; outlines procedures to aid verification by national technical means	Limits each side to no more than 2400 strategic missile launchers, heavy bombers, and air-to-surface ballistic missiles; constrains launch weight and throw weight of ballistic missiles; bans new ICBM development except one light ICBM	Photoreconnaissance satellites; over-the-horizon radar; Rhyolite signal intelligence satellites; other national technical means	USSR has exceeded launcher limits USSR is deploying two new missiles: SS-24 and SS-25 USSR is impeding U.S. verification by encrypting telemetry	Denial SS-25 is upgraded version of SS-13 Encryption protects secrets not covered by treaty	Pershing II and cruise missiles in Europe illegally circumvent treaty U.S. is developing two new ICBMs: MX and small ICBM (Midgetman)	Denial Midgetman is upgraded version of Minuteman

barks on new strategic directions."

Nevertheless, the Government has not studied whether it could verify whatever controls on Soviet ICBMs would be required to make the SDI viable, according to officials at the national weapons laboratories and other Government organizations. Indeed, one official at Los Alamos said the "verification problem" for a 50 percent reduction in strategic missiles—which the Reagan administration claims is its primary arms control goal—"is not solved yet." He added, "It'll probably never be entirely solved."

Disagreements about Soviet 'cheating'

The highly publicized divergences among Government officials over the extent and significance of alleged Soviet violations hints at the difficulties that those responsible for verifying future agreements—if any—will face. Technically, the President alone decides whether or not to formally charge the Soviets with a violation. He makes his decisions after hearing the intelligence reports of the Analysis Group, an interagency organization that is overseen by the National Security Council and includes representatives from the departments of State, Defense, and Energy; the intelligence agencies; and the Arms Control and Disarmament Agency (ACDA). Manfred Eimer, assistant director of verification and intelligence at ACDA and a cochair of the analysis group, said that President Reagan demands "incredibly high standards" of evidence before he accuses the Soviets of a violation.

Officials in the Defense Department—particularly Richard M. Perle, assistant secretary of defense for international security policy—have offered the most ominous interpretation of Soviet behavior. Perle has been a leading force behind the push to develop U.S. nuclear forces outside the bounds of agreements like SALT II and the ABM Treaty. In a Defense Department publication released last year, Perle accused the USSR of violating "almost all of the most important arms control agreements signed since 1963," and called U.S. adherance to these treaties "little more than unilateral disarmament." He also said there is "no question that Soviet arms control violations are militarily significant."

Perle's claims do not always jibe with information in unclassified sources. Last year, for example, he suggested to *Defense Week*, an industry newsletter, that Soviet underground tests are "systematically projecting radioactive materials into the atmosphere" in violation of the Limited Test Ban Treaty "about 40 or 50 times a year." (The United States has also violated this provision, but not since 1970, according to the Department of Energy.) However, according to the Stockholm International Peace Research Institute, the USSR has never exploded more than 31 nuclear devices underground—for both military and industrial purposes—within a year.

Not all U.S. Defense Department officials insist that the Soviet violations have much military significance. Fred C. Ikle, for example, under secretary of defense for policy and Perle's immediate superior, recently testified before the nuclear forces subcommittee of the Senate Armed Services Committee that the violations affected the "arms control process" more than the balance of military power. But Ikle and other officials claim that the violations are nevertheless disturbing.

"The treaties are written so that if there is a violation it won't upset the strategic balance initially," said ACDA official Eimer. "But say you are sleeping and you wake up and see your friend stealing $20 from your wallet. It may not hurt you financially, but it will certainly affect your relationship with your friend."

In public, the State Department has recently sided with the DOD and ACDA. But in a closed hearing in late 1984 John T. Chain, then the director of the State Department's bureau of politico-military affairs, testified before the Senate Armed Services Committee that the Soviets "have complied with the large majority of the treaties." He added: "I would hate to see this body walk out of here at the end of the day thinking of arms control as no good because the Soviets always cheat. That is not the position of the Administration. It is certainly not the position of the State Department."

Who really cares about verification?

Intragovernmental squabbles may affect not only how verification data is interpreted, but also how it is gathered. ACDA does not have the resources to gather compliance data itself. It depends on systems developed and used by the U.S. intelligence community and the military services. The systems needed to watch for violations of treaties are not always the same as those used for intelligence. The arms control agency submits its specific requirements to "very high levels" in the intelligence community, according to Eimer, but the agency doesn't always get what it wants.

"We have major differences," said Eimer, "with the other people who have intelligence requirements. We have to live with what we can get."

Although the Administration has argued that inadequate verification bars it from seeking agreements on antisatellite and chemical weapons and underground tests, it has allocated little for verification research. ACDA itself has an annual research budget of less than $1 million. Said Eimer, "We are supposed to do our work by influencing others." But the agency's influence is apparently not as persuasive as ACDA would like.

The Department of Energy provides the national weapons laboratories—Lawrence Livermore, Sandia, and Los Alamos—with about $100 million a year (slightly less this year) for research and development of verification technologies. Eimer complained that the laboratories "don't advise us; they're too busy talking to the press. Maybe they're talking to the Department of Energy, but the DOE doesn't play any role in this either."

Considering how much the Defense Department spends on intelligence, it has been relatively frugal with funds strictly for verification. Last year, the Defense Advanced Research Projects Agency set aside about $15 million for verification research, almost all of which went toward test ban studies. By contrast, the Defense Department allocated $16 billion for intelligence programs in 1985, according to a report in the *Armed Forces Journal* last year.

Lack of funding for verification of potential treaties creates what Lawrence Livermore's Nordyke calls a "chicken or egg problem." "It's a little hard to develop [verification schemes] that are valid under any agreement," he explained. "On the other hand, you can't reach an agreement unless you know whether it's verifiable or not."

Researchers at Los Alamos "are addressing probably twice as many specific problems now as we were six or seven years ago," said Robert Jeffries, head of verification and arms control programs at Los Alamos. With more money, Jeffries said, the laboratories could "maintain a strong, vigorous base technology so we can respond to changes in direction as fast as the politicians agree to it."

But those who decide where the money goes deny that they are being too frugal. "I don't see any reason to have an increase in verification funding until we see that the Soviets are going to be willing to allow us to verify," said Donald A. Hicks, who as undersecretary of defense for research and engineering oversees a $40 billion budget. "But the Soviets won't allow us to violate their territory."

Soviet stance on verification 'matures'

Hicks's remarks reflect a common misperception: that the Soviet Union was and is opposed to any sort of intrusive verification—measures that allow inspectors or U.S.-made sensors on their land. The USSR actually agreed to on-site inspections of nuclear test sites as early as the 1950s. But the Soviets would allow no more than three inspections a year; the U.S. wanted at least seven checks. The Soviets probably were not eager for arms control then, according to Heckrotte, the former test ban negotiator, because they feared it would freeze them into an inferior position. Heckrotte recalled that when he first went to Geneva in 1961 for comprehensive test ban talks, the Soviet attitude seemed to be: Just wait, the time will come when we will be stronger than you are. He added, "It was a dialogue that was going nowhere."

Indeed, from the 1950s through the 1970s, Heckrotte said, the test ban negotiations were "fairly stylized: the Soviets would say that on-site inspections were not necessary and we would say, 'They are too.' " The Soviets feared that the United States would use verification as an excuse to ferret out valuable secrets. But Heckrotte said he believed the Soviets had "matured" a great deal in the past 15 or so years.

The change came with the signing of two seminal treaties, the Threshold Test Ban Treaty in 1974 and the Peaceful Nuclear Explosions Treaty in 1976. The former was the first treaty to spell out cooperative measures for verification, including an exchange of information on test site geology. The latter was even more significant, because it would have allowed U.S. technicians to determine the size of nuclear blasts used for construction and mining by placing a sensor downhole, and to inspect sites where suspicious tremors had been detected remotely. Heckrotte said the U.S. negotiators worked hard to allay Soviet fears that inspections or in-country sensors would be used for espionage, and to ensure that the Soviets would have no way to subvert the verification process [see "Trying to overcome distrust with ingenuity," p. 71]. However, because these treaties have not been ratified by the U.S. Senate, the cooperative measures have yet to be carried out.

The Soviets' attitude toward the whole process of negotiating also evolved in the 1970s, according to Ralph Earle II, a chief negotiator of SALT II and the ACDA director in 1980 and 1981. "We Americans," he said, "grow up with contracts practically from the day we're old enough to read—insurance, leases, purchase agreements, credit cards. But the Soviets don't. At the beginning of SALT II we said to them, 'Look, we've got to have a section on definitions,' and they said, 'Why? Everybody knows what an ICBM is.' And we said, 'Maybe you think you know, and we think we know, but maybe we don't agree.' " Earle contended that SALT II "is quite a different treaty from SALT I, I think in part because the Soviets have become somewhat more accustomed to specificity."

More recently the Soviets have agreed to other on-site inspections. Last year, for the first time, they allowed inspectors from the International Atomic Energy Agency to check some of their older reactors. In June of this year they said that U.S. scientists—not Government representatives but private citizens—could monitor underground tests from seismic stations inside the USSR if the United States reciprocated by allowing Soviet scientists into the United States to monitor blasts at the Nevada Test Site. The agreement was negotiated by the Natural Resources Defense Council, a research group based in Washington, D.C.

Last Jan. 16, in announcing his plan to eliminate nuclear weapons, Soviet leader Gorbachev said: "Verification with regard to the weapons that are destroyed or limited would be carried out both by national technical means and through on-site inspections. The USSR is ready to reach agreement on any other additional verification measures."

The accident at the Soviet nuclear plant in Chernobyl has fueled suspicions that the Soviets are too secretive to be trusted. In a radio interview after the accident, Paul H. Nitze, special advisor to the President for arms control, said that Soviet handling of the incident "indicated the reluctance they have had toward any openness in their society." Nitze mockingly suggested that Soviet promises about verification referred to a time when the "triumph of communism" would allow KGB agents to roam the world at will.

But Marshal D. Shulman, director of Columbia University's Harriman Institute for Advanced Study of the Soviet Union, told the *New York Times* recently: "In all the 40 years I have studied the Soviet Union, I have not seen a time when they were more seriously interested in trying to get into negotiations with us. But it comes at a time when the United States is out of phase with that. We have been preaching to them for a long time on the virtues of arms control. But now we are in a period of nationalism and as a result nothing is coming of it."

Disputes over resolving disputes

Government officials also disagree over the extent to which private diplomacy can persuade the Soviets to change their behavior. The Standing Consultative Commission, an outgrowth of the Strategic Arms Limitation Talks in 1972, is the main forum for U.S. and Soviet diplomats to discuss compliance with treaties and other issues related to strategic arms control. The SCC meets twice a year—in Geneva and at the United Nations in New York—and more often if both nations desire.

Last November, in a memorandum sent to Reagan prior to his summit meeting with Gorbachev, Defense Secretary Weinberger lambasted the commission. "The SCC has failed to resolve any significant compliance issue in the approximately 1500 days it has been in session over the last 13 years," Weinberger declared. He called the commission "a diplomatic carpet under which Soviet violations have been continuously swept, an Orwellian memory hole into

II. Test ban treaties

Treaty and date signed	Parties	Significance	Provisions	U.S. verification technologies	U.S. charges of noncompliance	Soviet response to charges	Soviet charges of noncompliance	U.S. response to charges
Limited Test Ban Treaty Aug. 5, 1963	106 countries, including U.S. and USSR	First treaty to restrict nuclear weapons tests; verification aided by new satellite technology	Bans tests in atmosphere, in space, and under water; radioactive leaks from underground tests must stay within national borders	Satellite-based radiation and optical sensors; airborne radiation sensors	Soviet tests have led to venting of radioactive matter beyond borders	Leaks have involved not particulates but gases, which are permitted	U.S. tests have led to venting of radioactive matter beyond borders	There has been no venting beyond borders of U.S. since 1970
Threshold Test Ban Treaty July 3, 1974 (unratified by U.S., but both parties pledged to observe limit)	U.S., USSR	First treaty to include cooperative measures (exchange of information, etc.) for verification	Limits underground nuclear weapons tests to yield of 150 kilotons	Remote seismic sensing network; information exchanges, calibration tests (contingent on U.S. Senate ratification)	Soviet Union has tested above 150 kilotons	Denial	U.S. has tested above 150 kilotons	Denial
Peaceful Nuclear Explosions Treaty May 28, 1976 (unratified by U.S., but both parties pledged to observe limit)	U.S., USSR	First treaty to call for on-site inspections of nuclear explosions	Limits yield of individual blasts to 150 kilotons and yield of group blasts to 1500 kilotons	Remote seismic sensing network; on-site sensors (contingent on U.S. Senate ratification)	None ("peaceful" explosions used for Soviet construction)		None (U.S. has no "peaceful" nuclear explosions program)	

III. Treaties under negotiation

Subject of treaty; status	Parties	Objective	Potential verification measures	Current U.S. position	Current Soviet position
Strategic Arms Reduction; talks in progress	U.S., USSR	Fifty percent reduction in long-range offensive missiles	Photoreconnaissance; cooperative techniques (i.e., weapons tagging, "keep out" zones, on-site inspections)	Research for Strategic Defense Initiative program cannot be limited	U.S. "Star Wars" must be constrained before USSR offensive arsenal is reduced
Intermediate-Range Nuclear Force (INF); talks in progress	U.S., USSR	Limit or ban intermediate-range missiles in Europe, includ-mobile missiles	Same as above	Would eliminate all INF missiles in Europe if Soviet Union does; cannot speak for Great Britain and France	Would dismantle all intermediate-range missiles if U.S. does—and if Great Britain and France freeze missile levels
Comprehensive Test Ban; talks suspended by U.S. in 1980	U.S., USSR, UK	Ban all nuclear explosions	Remote seismic network; unattended in-country sensors; on-site inspections	Verification not feasible now; ban remains a long-term goal, but tests now required to upgrade arsenal	Soviet moratorium in force since last August; will extend if U.S. also halts tests
Antisatellite Weapons Ban; talks suspended by U.S. in 1980	U.S., USSR	Ban testing and deployment of antisatellite weapons	Ground-based and space-based reconnaissance; "keep-out" zones around satellites	Soviet Union possesses operational antisatellite weapons; a ban would freeze Soviet advantage and would be unverifiable	Seeks mutual ban on testing; sent proposal treaty to United Nations in 1983
Chemical Weapons Ban; talks suspended by U.S. in 1982	U.S., USSR	Ban development, testing, and possession of chemical weapons	Photoreconnaissance; space-based spectral analysis; unattended sensors; on-site inspections	New chemical weapons needed for safety reasons and to strengthen deterrence; unscheduled inspections necessary for verification	Will accept U.S. observation of decommissioning of stockpiles and designated production facilities; will not accept unscheduled inspections of other areas

Sources for the tables on treaties (above and on p. 75) include *Arms Control and Disarmament Agreement* (1982), and *Soviet Noncompliance* (Feb. 1, 1986), News and Views from the Soviet Union, Soviet Embassy, Information Department, Jan. 30, 1984; and interviews by *Spectrum* editors and researcher Rovert Davidson. Some arms agreements—such as the Antarctic and Seabed treaties—were excluded for lack of space.

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which our concerns have been dumped like yesterday's trash."

However, a book published in 1982 by the Arms Control and Disarmament Agency, which under Reagan has sided with the Defense Department on most issues, contradicted Weinberger's assertion, saying that the United States had used the commission to resolve numerous disputes over SALT I. "In each case raised by the United States," the book stated, "the Soviet activity in question has either ceased or additional information has allayed U.S. concern." An agency spokesman said the book, *Arms Control and Disarmament Agreements*, was a legacy of the Carter administration and is being revised.

A report released by the U.S. Congressional Research Service last spring spotlights some disagreements that were resolved. In the early 1970s, U.S. diplomats complained that the Soviets were deploying new submarine-launched missiles without dismantling other launchers, thus exceeding their limit under SALT I. The Soviets acknowledged that they had fallen behind in their schedule for dismantling land-based launchers, and agreed to the U.S. demand to halt deployment of the submarine-based missiles until they had caught up.

Soviet diplomats have also persuaded the United States to change its behavior. The USSR charged in the mid-1970s that the U.S. was illegally impeding Soviet surveillance of an upgrading of Minuteman II silos by covering them with shelters. Subsequently, the United States made the shelters small enough for the Soviets to monitor the construction.

Representative George Brown (D-Calif.), a member of the U.S. House Select Intelligence Committee, suggested that the Administration is to blame if the Standing Consultative Commission has recently been ineffective. The current commissioner of the SCC, Richard H. Ellis, told the committee in a closed hearing last November that he had been discouraged from trying to resolve disputes with the Soviets by Administration officials, Brown told *Spectrum*. Ellis testified that he believed the Soviet compliance record had been reasonably good, said Brown. Referring to the fact that Ellis had headed the Strategic Air Command from 1977 to 1981, Brown said, "If I have a choice of the opinion of the SAC commander and Richard Perle I'll take the SAC commander every time."

Making verification international

Is there any way to depoliticize verification, to make the interpretation of data less susceptible to manipulation? Some students of arms control have suggested that an international organization could provide a more impartial, less rancorous means of settling compliance issues. Such an organization would have access to intelligence data, perhaps in limited amounts, and could also participate in on-site inspections and other intrusive programs.

A possible model for a multilateral verification scheme is the Safeguards Program of the International Atomic Energy Agency (IAEA), set up to monitor compliance with the Nuclear Non-Proliferation Treaty. Signers of the treaty pledge not to divert nuclear materials from power plants and other nonmilitary nuclear facilities into weapons programs—their own or any other nation's. The treaty is verified through periodic inspections by teams of IAEA officials and the emplacement of unattended television cameras and tamper-proof seals in designated facilities.

Kosta Tsipis, director of the program in science and technology for international security at the Massachusetts Institute of Technology in Cambridge, has proposed that an international reconnaissance satellite could help resolve international disputes about arms control. Argentina, Sweden, Mexico, India, Tanzania, and Greece—often called the Group of Six—have proposed to jointly administer such a program.

Tsipis said that when the concept of multilateral verification was first proposed in the late 1970s, "the United States and USSR were very unhappy with it." But now, as nations like West Germany, France, and Japan develop the capability to launch high-resolution satellites, the Group of Six may proceed with their plan "independently of the superpowers," Tsipis said. He noted that French officials have already said they would "be delighted" if Spot—the new commercial satellite launched by France's Arianespace Inc. last January—were used.

James A. Schear, a fellow at Harvard University's Center for Science and International Affairs and a former ACDA staff member, opposed Tsipis's international satellite concept. "It won't provide better intelligence than we already have, so it won't satisfy skeptics." He said that for certain issues, such as monitoring the production or use of chemical weapons, the United Nations could be an effective tool. But for agreements "that most concern the United States and the USSR," Schear said, "I don't think a third party would help much. Pakistan would want to get data on India and vice versa."

Multilateral nuclear weapons agreements may become a necessity rather than an option. China, Great Britain, and especially France are all modernizing their nuclear forces. Recently French officials announced that a submarine had successfully launched a missile to deliver multiple warheads almost 4000 miles away. Some of the new missiles have already been deployed in French nuclear-powered submarines. Other nations—including Israel, Pakistan, and South Africa—reportedly have nuclear weapons or the ability to build them.

"We definitely need some sort of multilateral compliance mechanism for multilateral agreements," said Krepon of the Carnegie Endowment, adding that he was more concerned that a "third country" would start a nuclear war than either the United States or USSR. But for verifying agreements between the superpowers, Krepon said, "I don't think third parties would be very helpful."

Cruise missiles: the more the better?

Cruise missiles—small and easy to move—epitomize the technical problems facing arms controllers of the future. Cruises are far more worrisome than mobile intercontinental ballistic missiles, according to most experts. Schear, the Harvard researcher, explained that the United States "has a pretty good idea how to track mobile ICBMs. They have a long logistics trail."

Some experts question the value of trying to limit cruise missiles, arguing that they stabilize relations between the superpowers. In a sense, cruise missiles are the ideal weapon to back up a policy of mutual assured destruction. They are too slow to destroy military targets in a first strike; early-warning technology could spot an attack from the subsonic missiles long before they could reach missile silos deep within the continental United States or USSR. Nor do they tempt a first strike as large, multiwarhead missiles placed in silos do.

But allowing cruise missiles to proliferate would be "self-defeating," according to Paul Warnke, who directed the Arms Control and Disarmament Agency from 1977 to 1978. "The real difficulty is that you'd never know what the other side had, and since you'd never know whether you had enough, you'd have to keep building them."

Moreover, because cruise missiles launched from submarines or other ships off the U.S. coast could strike some military targets within minutes, "it isn't at all clear that they are as stabilizing as we think they are," said Schear. He added that surface-launched cruises, which can be launched from even small fishing trawlers, are more of a problem than submarine-launched cruises.

Verifying controls of the cruise missiles, say arms controllers, will almost certainly require cooperative measures. These include on-site inspections, monitoring of production facilities, or the restriction of launchers—whether ships or submarines or trucks—to designated zones.

Warnke said that a total ban on sea-launched missiles, together with "challenge inspections," would be the best solution. "You would have the right to board a ship," Warnke explained, "and if they refused, you would consider that a violation. If we're going to go further with the arms control regime, you will have to have more intrusive measures."

Not all experts agree that on-site inspections would provide a better form of verification than remote sensing for weapons

Twenty-five years old and still struggling with an identity crisis

In 1961, prodded by Senator Hubert H. Humphrey, the U.S. Congress created the Arms Control and Disarmament Agency and gave it "primary responsibility" for formulating arms control policy, negotiating treaties, and verifying compliance. To monitor agreements like the ABM and SALT II treaties, the agency usually relies on intelligence gathered by other organizations. But ACDA (pronounced Ack-duh) representatives occasionally fly to the South Pole to see for themselves that Soviet scientists camped there have not hidden nuclear weapons in their Quonset huts, in violation of the 1959 Antarctic Treaty.

Heavy mission, lightweight budget

Considering its weighty mission, the agency's budget is relatively slim. This year (when ACDA requested $25 850 000), Congress gave it $24 738 000, or less than one-tenth of the total estimated cost of one B-1 bomber. Most of ACDA's 184 employees are buried within the massive headquarters of the Department of State in Foggy Bottom, a Washington, D.C., neighborhood. And though the agency is intended to be an independent advisory body, its director—now Kenneth L. Adelman, a deputy to United Nations Ambassador Jeane D. Kirkpatrick in the Reagan administration's early years—has twin allegiances: appointed by the President, he is expected to give the commander in chief apolitical, expert advice; but he reports to and can be reprimanded by the Secretary of State.

'Immutable conflicts' blamed

Some observers liken ACDA to an aging adolescent, forever agonizing over its purpose in life. In an article for *Foreign Affairs* in 1983, Barry M. Blechman, assistant director of ACDA from 1977 to 1980, and Janne E. Nolan, who also worked for ACDA under President Jimmy Carter, wrote: "From its inception, ACDA was supposed to be both an integral part of the executive branch and a watchdog over its activities; a component of the State Department and an independent agency reporting directly to the President; a promoter of the modest idea of arms control and a partisan for the radical policy of disarmament." These "immutable conflicts," Blechman and Nolan argued, kept the agency from fulfilling any useful role at all.

They recommended that the agency be abolished and its responsibilities reassigned to other Government organizations, like the State Department and Congress. "It is time to integrate arms control with the rest of the nation's security agenda," they declared.

But Gerard Smith, who directed the agency under Nixon and was the chief U.S. negotiator of the SALT I agreement, said that no Federal organization could pursue arms control independently of its commander in chief. "I think that was the hope of Senator Humphrey" in creating ACDA, Smith said, "but it's hard if the President says, 'This is my policy. Don't get out of line.' " ACDA or no ACDA, Smith said, arms control would languish "under the present leadership." —J.H.

like cruise missiles. Earle, the former ACDA director, suggested that inspectors could be easily fooled. Usually far superior, he said, is the combination of national technical means and the "worst case" counting rules developed under SALT II—which stipulate, for example, that if one plane is used to carry cruise missiles, then all planes of that class are counted as cruise launchers. Earle added, "What I'm really against is people who say that your next treaty with the Soviet Union must provide for on-site inspections."

Lawrence Livermore's Nordyke agreed, saying, "If you're dealing with an on-site inspection, they'll never let you find a violation." But he said that inspections can help "build confidence" and, most important, raise the costs of cheating. "Everything is driven by money," said Nordyke.

Meanwhile, defense engineers are designing a new generation of cruise missiles that may be more dangerous. Already able to evade detection by hugging the ground, they will be made even more invisible or "stealthy" with the addition of jamming equipment and nonreflecting coatings. They will be capable of accelerating to supersonic speeds as they approach their targets, according to the *Nuclear Weapons Data Book*. Moreover, both the USSR and the United States are adding thousands of cruise launchers to a wide variety of ships and submarines.

According to the U.S. national laboratories, no studies are under way for determining how a treaty limiting or banning cruise missiles could be verified.

Building mutual confidence

Even if they are verifiable, of what use are treaties if they do not halt or even slow the incessant advances of destabilizing military technology? Such fundamental questions have led many who have traditionally supported arms control to believe that the whole process has failed and needs rethinking. A 1983 report by the Carnegie Endowment for International Peace noted that arms control has been "discredited at both ends of the political spectrum. Many liberals were disillusioned that arms control had, in their view, accomplished so little. Conservatives charged arms control with other sins—lulling the American people into a false sense of security, even euphoria."

Brown of the U.S. House said that although he is a "confirmed arms control enthusiast," he believes that arms control is "less important as a process than enhanced communication, trade, and various other things that will help build confidence."

Other congressmen are similarly inclined. Senators Sam Nunn (D-Ga.) and John Warner (R-Va.), both members of the Senate Armed Services Committee, have proposed that the United States and USSR move in this direction by building "nuclear risk reduction centers."

Staffed by military and intelligence experts from both countries, the centers would promote the exchange of military information and the resolution of situations that could ignite a nuclear confrontation. The proposal specifically addressed the possibility that terrorists could build or steal a nuclear weapon and use it to spark a war between the United States and the USSR. U.S. officials have conducted informal talks with the Soviets to explore how the risk reduction centers might be organized.

Last year Senator Gary Hart (D-Colo.) proposed that both the United States and the USSR jointly pursue a "Manhattan Project for verification," which would seek both technological and political breakthroughs that would enhance bilateral verification and promote stability.

Holding back military innovation

Such bilateral projects may provide a more secure political base for arms control negotiations of the future. But to check the arms race, future leaders must do more than just limit the numbers of weapons, according to some scholars.

In a paper published in 1983 by the Worldwatch Institute, a nonprof[illegible]ch group based in Washington, DC, Daniel Deudney wr[illegible] "Most arms proposals set forth by the super powers have been fairly transparent attempts to gain advantage by constraining only weapons the other side enjoys a lead in. . . Even when the superpowers accept a principle of mutual advantage and negotiate seriously, they have typically sought treaties with loopholes for continued innovation in armaments (euphemistically called 'modernization')."

Indeed accuracy, that most vital component of a first-strike weapon, has never been limited. The United States did not want to restrict accuracy in the SALT II talks, according to Earle, because its smaller warheads made it "more dependent on accuracy than the Soviets." Earle agreed that limiting accuracy would be stabilizing, but doubted that such a step could be justified to the military. Limiting the accuracy of missiles, he added, "is like saying no soldier will be able to hit a bull's-eye with his rifle. It

CHEMICAL AND BIOLOGICAL WEAPONS: THE OTHER ARMS RACE

Nuclear weapons are not unique in their power to kill by poisoning. Chemical and biological weapons share that distinction. Chlorine and mustard gas—used first by the Germans and then the Allies—killed or injured more than 1 million soldiers and civilians in World War I. Horror at these casualties spurred negotiators of the Geneva Protocol in 1925 to ban first use of chemical and biological weapons. Nevertheless major industrial powers continued to develop, produce, and stockpile deadly gases. Relatively primitive systems—usually tanks of mustard gas, which blinds victims and burns the skin—gave way to modern arsenals—bombs, artillery shells, and rockets containing nerve gases that kill within minutes.

From anthrax to killer mosquitoes

Biological weapons were slower in coming. The U.S. began cultivating anthrax as a weapon toward the end of World War II, according to Julian P. Robinson, a chemist and senior research fellow at the University of Sussex, Great Britain, who has studied the history of chemical and biological weapons for over 20 years. These extremely poisonous bacteria were packed into "cluster bombs." Plummeting toward its target, the "mother bomb" would expel its cluster of parachute-fitted "bomblets," which would float to earth, burst, and release their payload. Anthrax was chosen for its virulence and longevity. Robinson noted that an island off Scotland where anthrax weapons were tested in the 1940s is still "off limits."

During the 1950s, said Robinson, the U.S. Strategic Air Command stockpiled germ-filled cluster bombs built by the Army to complement its atomic weapons. SAC plans called for bombers to drop both nuclear and biological weapons during an attack, he explained, creating a "wall of disease" around the blast zone. With the advent of high-yield fusion bombs, the Air Force lost interest in biological warfare, said Robinson.

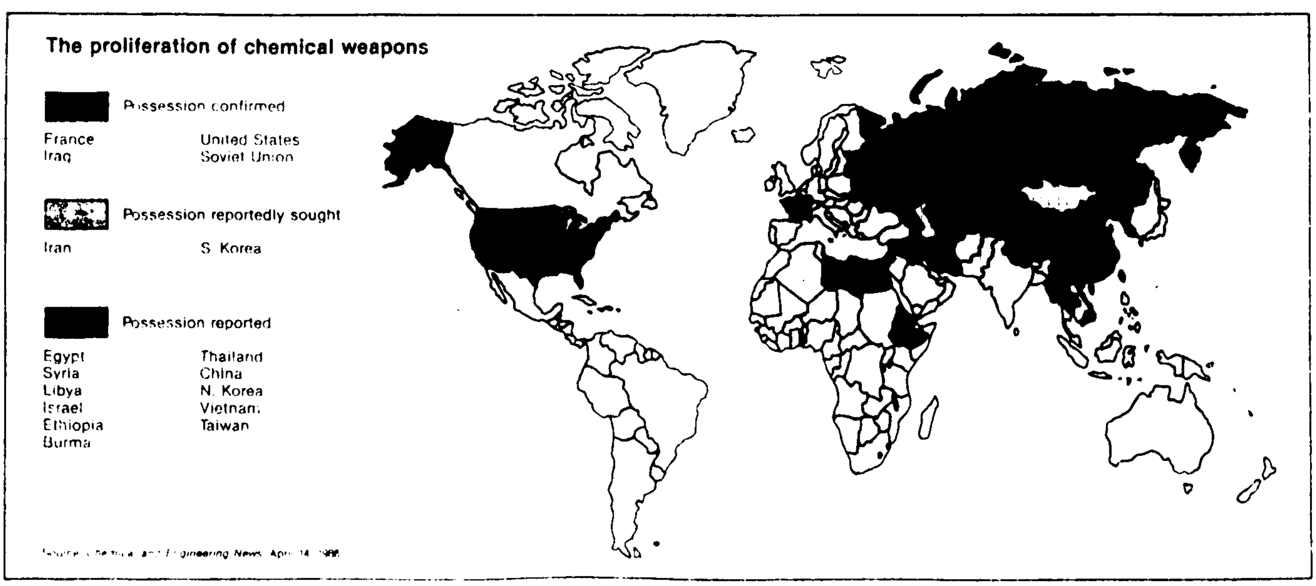
But the Army continued developing more sophisticated ways to deliver germs, including crop-duster sprayers, rockets, and remote-controlled drones. Microbes that caused diseases like brucellosis, viral encephalitis, and Q fever—which usually sicken rather than kill victims—were cultivated and occasionally tested on volunteers from prisons and the military, Robinson said. The Army bred mosquitoes tainted with deadly yellow fever germs and designed warheads that could release the live insects over a distant target. Engineers also devised "gadgets"—like aerosols and bullets filled with lethal organisms—for small-scale, clandestine operations, Robinson said. The Central Intelligence Agency stockpiled tiny darts tipped with a shellfish poison as recently as the mid-1970s.

Disputes over Agent Orange and yellow rain

Over the past 20 years the superpowers' efforts to ban chemical and biological weapons have been marred by mutual recriminations and, recently, a renewed buildup. During the Vietnam War the USSR charged that the United States had violated the Geneva Protocol by using herbicides—such as Agent Orange—and tear gas in Vietnam. A majority of United Nations members supported the Soviet view. Soon after, in 1969, President Richard M. Nixon unilaterally halted U.S. production of lethal and incapacitating chemical weapons (incapacitants included LSD-like hallucinogens) and declared the United States would not use them first. Nixon also ordered that all U.S. biological and toxin weapons be destroyed. Three years later the United States and the USSR signed the Biological Weapons Convention, pledging not to produce, stockpile, or use "microbial or other biological agents or toxins," the latter defined as poisons made by living organisms.

In 1980 the U.S. accused the Soviets of violating the treaty. State Department officials claimed that anthrax that poisoned hundreds of Soviets near the city of Sverdlovsk in 1979 had leaked from an illicit factory. In 1981, the Reagan administration charged that Soviet troops in Afghanistan and Communist Vietnamese fighting insurgents in Southeast Asia had sprayed their enemies with toxins—which some alleged victims called "yellow rain"—from the USSR.

These U.S. charges have been as hotly disputed as those concerning Soviet compliance with nuclear treaties, and they remain unproved, according to Matthew Meselson, a professor of biochemistry at Harvard University who was a Government consultant for biological and chemical warfare from 1963 to 1981. Meselson studied classified reports of the Sverdlovsk incident and concluded that the



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just flies in the face of all military training and goals."

U.S. negotiators also rejected Soviet attempts to ban cruise missiles because that would have meant sacrificing the U.S. advantage in that technology, according to Admiral Stansfield Turner, CIA director from 1976 to 1981. "Our reluctance, not the Russians'," Turner told *Spectrum*, "kept the limits on mobile and cruise missiles minimal."

The desire to explore new weapons technologies at the expense of arms control is often couched in humanitarian rather than military terms. Almost 30 years ago Edward Teller, a chief architect of the U.S. hydrogen bomb and today a leading proponent of "Star Wars," sought to persuade President Dwight D. Eisenhower not to ban tests of nuclear weapons. In a press conference in 1957, Eisenhower informed reporters that Teller had told him that U.S.

Soviets' explanation could "not be ruled out" by the U.S. government's evidence. "We don't know what happened," he said.

As for yellow rain, separate investigations by the United Nations, Canada, Great Britain, and South Africa, among other nations, have failed to corroborate the Reagan administration's claims. At least two studies determined that—contrary to the Reagan administration's scenario—the toxins that had sickened Cambodian and Vietnamese villagers were indigenous to Southeast Asia. After extensive research of his own, including a trip to Cambodia, Meselson concurred with other scientists that yellow rain was bee feces. The Government's case, he contended, "has collapsed."

Doubts about a 'doomsday bug'

Nevertheless, the latest edition of *Soviet Military Power*, the U.S. Defense Department's periodic report on Soviet forces, reiterated charges that the USSR and its surrogates had used toxins and chemical agents. It also suggested that the USSR might be experimenting with gene-splicing techniques to create "a predictable, controllable, and effective biological warfare agent." A Reagan administration official privately elaborated: "We're not as concerned about the Soviets building some new doomsday bug as we are about them trying to improve on what's already there"—that is, organisms like anthrax. Moreover, a 1984 report by the U.S. Army stated that, while the U.S. chemical arsenal has languished since Nixon froze it in 1969, the USSR "has continued to amass the greatest offensive and defensive chemical capability of any nation." Officials have also said privately that the USSR is behind the proliferation of chemical weapons in the Third World (see map).

The U.S. Defense Department has tried to parlay these claims into congressional support for a multibillion-dollar upgrade of its own chemical and biological warfare programs. The Army is expanding a facility for research into defenses against biological warfare at the Dugway Proving Grounds in Utah. Craig C. MacNab, an Army spokesman, said that, in order to test the effectiveness of vaccines, early-warning sensors, and protective gear, Army scientists must grow the toxins or microbes that U.S. intelligence says the Soviets have. He said that deadly germs spawned at Dugway could not serve as weapons. "We could give a test tube full of the stuff to a terrorist and have him go stand in a bus station in Minsk," MacNab said, "but that's not a delivery system."

For at least two years Army researchers have experimented with gene splicing, which can create organisms that do not occur in nature. Meselson, whose research at Harvard includes recombinant DNA experiments, said that gene manipulation might help create vaccines, but would be less useful for concocting microbes deadlier than those found in nature. "If you do recombinant DNA work on an organism you usually make it weaker," he said.

Flaws found in new nerve gas bomb

The most controversial and costly part of the U.S. Army's upgrading would end the freeze that Nixon imposed on production of chemical weapons in 1969. In its 1987 budget, the Defense Department asked Congress for $330 million—out of a total of $1.34 billion sought for all chemical and biological warfare programs—to begin manufacturing a new generation of weapons, called binaries. Military officials contend that the current stockpile of chemical weapons—which includes tens of thousands of bombs and artillery shells and huge tanks of gas stored in Europe and the United States—is unsafe and obsolete. These so-called unitary weapons have a single chamber filled with deadly gas, whereas binary weapons have two reactants—neither of which is lethal in itself—that must combine to create the nerve gas. One reactant is stored in the weapon casing, and the other in a canister that is inserted into the warhead shortly before it is fired.

The Army wants three types of binary weapons: a short-range artillery shell; a medium-range multiple-launch rocket; and a bomb, called Bigeye, for attacks deep behind an enemy's lines. About a year ago Congress reluctantly approved funds for Bigeye production, but in October it rescinded its approval. One reason: the U.S. General Accounting Office had uncovered technical flaws in the Bigeye that suggest it may not be either as safe or as militarily useful as the weapons it is supposed to replace. The GAO found that in some tests, the mixing of chemicals (not actual nerve agents but simulants) caused a buildup of pressure that ruptured the Bigeye before it was dropped from the plane; in other tests the reactants did not mix well enough to produce the required lethality. After reading a more recent study released last month, Dante Fascell (D-Fla.), chairman of the U.S. House of Representatives Foreign Affairs Committee, told *Spectrum* the Bigeye was "a persistent failure with no prospect of ever working properly or safely."

Nevertheless Congress has indicated that it might grant money for production if the Defense Department can demonstrate that Bigeye's flaws have been eliminated and that the vast stores of aging unitary weapons can be safely destroyed. The latter may be the more difficult task. Army spokesman MacNab called it a "nightmare problem"; another knowledgeable official said that "destruction of chemical weapons is a science, but not a very exact one." The Army has estimated that the job will take seven years, at a cost of $1.7 billion to $2.1 billion. Congressional experts say the cost could be five times that high.

Talks snag on verification concerns

Both the United States and the USSR continue to proclaim their desire for a treaty banning the production and possession of chemical weapons. Talks have continued on and off in Geneva. As usual, the negotiations have snagged on verification. Three years ago the USSR agreed to allow U.S. inspectors access to designated chemical weapons plants for up to 10 years, to ensure that all stockpiles and production facilities had been destroyed. But the talks broke down when the Soviets refused to allow inspectors to investigate any location within the USSR on 24 hours' notice.

Officials at the U.S. national laboratories believe that technology can help break the stalemate. Robert Jeffries, head of verification and arms control programs at Los Alamos National Laboratory in New Mexico, said the laboratory had studied some promising classified techniques but needs more money to develop them further. In 1984 the National Research Council, with money from the Army, sponsored a study of sensors to detect chemical or biological weapons on a battlefield. The "most promising" technologies cited were: solid state microsensors with coatings that interact with specific toxic compounds; immunoassays that use antibodies to identify biological agents; and laser-based systems that can determine the composition of suspect clouds by reflecting beams of light off them.

Presumably such technologies could be adapted for spot inspections or for unattended monitoring of dismantled production facilities. An Administration official acknowledged that "there isn't much money out there" to study how these or any other systems could monitor a treaty. The total U.S. budget for research into verification of a chemical weapons ban, he said, is less than $1 million.

Ivo Spalatin, staff director of the arms control subcommittee in the House Foreign Affairs Committee, stressed that technology alone would not lead to a treaty anyway. "This is not a technical problem," he said. "This is a political problem." Spalatin deplored the renewed U.S. interest in biological and chemical weapons—especially the binary weapons—as a moral and military retreat from Nixon's unilateral actions in 1969. "There is little or no military usefulness" for chemical or biological weapons, said Spalatin. Because the user's troops must also don protective gear, Spalatin said, "the degree of degradation imposed on the user is almost equal to the degradation to the recipient. It reduces their effectiveness by about 50 percent." It was this realization, certainly not moral misgivings, Spalatin added, that kept Adolph Hitler from using his nerve gas during World War II.

J.H.

scientists could build a "clean" bomb within "four or five years."

"If you use this on the battlefield," Eisenhower explained, "there will be no fallout to injure any civilian."

Today military officials argue that continued testing can make warheads smaller and more precise thereby limiting "collateral damage." Tests are also crucial, they say, to develop the Strategic Defense Initiative, which Reagan referred to last February as "the program that could free us all from the prison of nuclear terror."

Perhaps when world leaders realize that technology alone—whether "clean" bombs or space-based lasers or even satellites that can read newspaper headlines—cannot end the arms race, utopian declarations will be more than just rhetoric. ◆

TO PROBE FURTHER

Though it is a highly secretive endeavor, there is a fair amount of information on strategic arms verification to be found in the open literature.

• **General:** A good primer is *The Verification Challenge*, edited by Richard Scribner et al., American Association for the Advancement of Science (Washington, D.C., 1985). *Verification: How Much is Enough?* by Allen S. Krass (Taylor & Francis, Philadelphia, 1985) is similarly useful. A more technical book, *Arms Control Verification: The Technologies that Make It Possible* (Pergamon-Brassey, New York, 1986) is based on a symposium held at the Massachusetts Institute of Technology. *Verification and Arms Control* (D.C. Heath & Co., Lexington, Mass., 1985), edited by William Potter, is also worth examining, but is generally less comprehensive than his ground-breaking 1980 book, *Verification and Salt: the Challenge of Strategic Deception*. "Challenges for U.S. National Security," a concise 1983 report by the Washington, D.C.-based Carnegie Endowment for International Peace, is worthwhile. The landmark open testimony of the SALT II Verification hearings, held in July 1979 before the U.S. Senate Committee on Foreign Relations, is a mine of information.

Useful periodicals on the subject are *Science*, (AAAS, Washington, D.C.), *Scientific American* (New York), and the *Bulletin of Atomic Scientists* (Chicago). Two especially interesting articles in the latter are: "Old surveillance, new interpretations," by Jeffrey T. Richelson (February 1986 issue) and "Arms control: necessary process" by Wolfgang K.H. Panofsky (March 1986). *Arms Control Today*, a monthly magazine of the nonprofit Arms Control Association, Washington, D.C., is also valuable. (Also inquire about their publication "Countdown on SALT II.") *IEEE Spectrum*'s special issues "Space 25," September 1983, and "Technology in War and Peace," October 1982, are of general interest.

• **Weapons counting:** *Sky and Telescope* publishes frequent articles on the civilian space telescope (check the April and May 1985 issues). "Concepts for Large Interferometers in Space," a paper presented at an Oct. 4–6, 1982, conference looks beyond the space telescope. Reprints are available from the American Institute of Aeronautics and Astronautics, New York City. The American Society of Photogrammetry, Falls Church, Va., publishes the *Manual of Remote Sensing*.

The IEEE Geoscience and Remote Sensing Society's July *Transactions* is devoted to the Shuttle Imaging Radar. The Seasat radar is described in a November 1982 *Spectrum* article by Charles Elachi and James Granger. Readers interested in the history of the U.S. photoreconnaissance satellite program should consult Jeffrey T. Richelson's article in the June 1984 issue of *The Journal of Strategic Studies*, a scholarly review published in London by Frank Cass & Co. Ltd. For those visiting Washington, D.C., the U.S. Smithsonian Institution's National Air and Space Museum recently opened a major exhibit, "Looking at earth." The exhibit, featuring reconnaissance from nineteenth century balloons to space-age satellites, is expected to be on view for some 10 years. For information, call 202-357-3266.

• **Test monitoring:** For electronic surveillance, *The Puzzle Palace* (Penguin Books, New York, 1982) by James Bamford is the authoritative classic on the National Security Agency. "Electronic Warfare: How We Monitor the Soviet Arsenal," in the September 1979 issue of *MicroWaves* magazine is a good source for telemetry intercept and radar techniques.

Desmond Ball, the director of the Strategic and Defense Studies Center at the Australian National University, has written two incisive papers about verification: "The Rhyolite Program" (reference paper 86), 1981; and "The Comprehensive Test Ban (CTB) Treaty: a Role for Australia," presented at the Conference on the Future of Arms Control in August 1985. Contact the University's Research School of Pacific Studies, Canberra ACT 2601, Australia.

For seismic monitoring, Sandia and Lawrence Livermore National Laboratories, in Albuquerque, N.M., and Livermore, Calif., respectively, publish informative newsletters. Recent ones devoted exclusively to arms control verification are Sandia's November 1984 issue and Livermore's May 1983 issue. "Comprehensive Final Report for the Marine Seismic System Program" is just that—a detailed look at research sponsored by the U.S. Defense Advanced Research Projects Agency. It was published in August 1985 by the U.S. Naval Ocean Research and Development Activity in Mississippi.

• **Soviet capabilities:** *The Soviet Year in Space*, 1985, by Nicholas L. Johnson at Teledyne, Brown Engineering, Colorado Springs, Colo., outlines in some detail launches and unusual activities of Soviet intelligence satellites.

• **Issues:** *Arms Control and Disarmament Agreements*, a history of negotiations replete with treaty texts, is an indispensable reference and surprisingly accessible (latest edition 1982). It is published by the U.S. Arms Control and Disarmament Agency, Washington, D.C. On current Administration policy, few items are more informative than briefs and speeches published by the U.S. State Department (public affairs office, 202-647-6575). *Nuclear Arms Control* (National Academy Press, Washington, D.C., 1985) by a National Academy of Sciences panel reads like a committee report but is still useful. "Arms Control," a special Sept. 14, 1983, edition of the U.S. Defense Department's *Current News*, takes a pragmatic if not skeptical view of arms control. "Worldwatch Paper 55: Whole Earth Security: A Geopolitics of Peace," by Daniel Deudney, published by the Washington, D.C.-based Worldwatch Institute, July 1983, is an intensively researched 93-page report that offers an alternative view.

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The opening illustrations for the four sections of this report are: (1) SR-71 Blackbird reconnaissance jet; (2) streaking reentry vehicles during a missile test; (3) Soviet Bear-H bomber, a platform for cruise missiles; (4) the launching of a cruise missile from a submerged U.S. submarine off the California coast. (The source for all four photos is the U.S. Department of Defense.)